United States
Department of
Agriculture

Forest Service

Southeastern Forest
Experiment Station

General Technical Report
SE-70

Proceedings of the Sixth Biennial Southern Silvicultural Research Conference

Memphis, Tennessee
October 30 - November 1, 1990

Volume 1

PREFACE

This document presents research investigations of 256 scientific professionals studying patterns and processes of managed southern forests through 95 reported studies. These contributions emanate from formal researchers, extension, and staff specialists, and forest managers. Authors represent a cross section of universities, forestry and horticultural companies, and public agencies. Their approaches and findings are worthy of study and, where appropriate, incorporation into the logical system we call silvicultural literature.

Three invited general session presenters addressed the challenges to forestry in the South from the viewpoints of federal, industrial, and nonindustrial private forest managers.

An exciting field tour to the Ames Plantation on the third day of the conference was hosted by the Ames Foundation and the University of Tennessee. Those attending expressed appreciation for the opportunity to observe the forest and wildlife research and demonstration sites on the Plantation.

Acknowledgments are made to the conference cochairpersons, James Purdue and Gordon Lewis, Southern and Southeastern Forest Experiment Stations, and the steering committee, composed of the following representatives and their sponsoring organizations:

Doug Crutchfield, Westvaco Corporation, Summerville, SC

Chuck Hollis, International Paper Company, Bainbridge, GA

Jim Baker, SOFES, Monticello, AR

John Toliver, SOFES, Stoneville, MS

John Hodges, Mississippi State University, MS

Marilyn Buford, SEFES, Charleston, SC

Dean Gjerstad, Auburn University, Auburn, AL

Dave Smith, Virginia Polytechnic Institute and State University, Blacksburg, VA

John Pitcher, Hardwood Research Council, Memphis, TN

The diligence and thoroughness of these individuals are to be commended. Special recognition is also offered to the superb panel of distinguished moderators that led each session.

Papers published in this proceedings were submitted by the authors in electronic media. Limited editing was done to ensure a consistent format. Authors are responsible for content and accuracy of their individual papers.

Daniel G. Neary
Program Chairperson
Southeastern Forest Experiment Station

Proceedings of the Sixth Biennial Southern Silvicultural Research Conference

Volume 1

Compiled and edited by
Sandra S. Coleman and Daniel G. Neary

Memphis, Tennessee
October 30 - November 1, 1990

Sponsored by

Southeastern Forest Experiment Station
Southern Forest Experiment Station

Southern Region of the
National Association of Professional
Forestry Schools and Colleges

Southern Industrial Forestry
Research Council

Silvicultural Working Group--
Society of American Foresters

Hardwood Research Council

Published by

Southeastern Forest Experiment Station
Asheville, North Carolina
September 1991

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LVICS: Soil Site Relations

Volume 2

SILVICS: Ecophysiology

MULTIRESOURCES: Tree Improvement

MULTIRESOURCES: Wood Technology

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CAUTION: PESTICIDES

THE ROLE OF RESEARCH IN ADDRESSING CHALLENGES TO SOUTHERN SILVICULTURE [1]

Jerry A. Sesco and Nelson S. Loftus, Jr. [2]

Summary. This paper discusses society's challenges to and opportunities for silviculture, in the '90s and beyond, and the unique role researchers will play. Challenges include those social and political factors causing foresters to examine how they practice forestry; and a strategy for meeting those challenges for USDA Forest Service Research. Opportunities include learning, growth, and development in a field that is never static; incorporating past management experiences into the present and future mix of uses and values for a changing world.

Introduction

I appreciate the opportunity to ticipate in this Sixth Biennial thern Silvicultural Research Conence. I am pleased and honored e part of what promises to be an ellent session on silviculture. gives me the opportunity to share n you some of my thoughts about est Service Research and our rey released "Strategy for the s."

In the time I have this morning want to briefly discuss four nts:

1. Society's challenge to silviture and our role as researchers.

2. The social and political factors that are causing us to change how we practice forestry.

3. "Strategy for the 90's for USDA Forest Service Research."

4. The opportunity for silviculture in the 1990s and beyond.

What Are the Challenges? What Is Our Role?

There is a changing land ethic in how people look at natural resources. Although this change is now mainly directed at public lands, passage of forestry practices acts now being considered by many States, especially in the West, will eventually influence how private forest lands are managed. This change was discussed in Associate Chief George Leonard's opening paper to your Fifth Conference. In his paper entitled, "The 2030 Forest: USDA's Role" he called for new and additional research to meet anticipated demands

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aper presented at Sixth Biennial thern Silvicultural Research Conence, Memphis, TN, Oct. 30-Nov. 1990.

Deputy Chief for Research and ncipal Research Silviculturist, A Forest Service, Washington, .

on the South's forest resources. He also noted that there would be more "urban" people living in "rural" areas and they would be concerned about what is happening in the forests around them. In his recent speech to the 19th IUFRO Congress, George Leonard again stressed the land manager's need for science because of unalterable changes in the environment in which forests grow and the diverse ways people now expect forests to serve them at local, regional and global scales. Another indication of this demand for change can be found in the Research Council's Report, "Forestry Research: A Mandate for Change," which calls for forestry research to play a major role in addressing an array of societal needs and concerns for the forest. There is a call for a new research philosophy, that is, an environmental philosophy. In response to this call and to the shifting needs of people the Forest Service and the direction of our programs are changing. Strategic guidance for these changes comes from the Recommended 1990 RPA Program and our Research Strategy for the '90s.

As resource managers, researchers, and administrators we face many challenges in carrying out our missions. As **resource managers** our challenge is simply this: Multiple-use management with greater environmental sensitivity. This theme was central to the Southern Forest Productivity Program jointly developed by the Forest Service and southern university researchers in 1988. As **researchers** our challenge is to provide answers to increasingly complex questions without compromising our scientific independence and credibility. Our role is then to provide the information and technology needed, indeed required, to sustain the quality and quantity of multiple-forest and grassland resources. Finally, as **administrators**, our challenge is to provide the leadership and direction necessary to be competitive for resources and scientific standing, and to be responsive to the needs of our cooperators and clients. These challenges are accompanied by opportunities to change the way we practice forestry and to increase the breadth of our research programs and the depth of our investigations.

Motivation for Change

Until the latter part of the 1960s, the primary focus of forest management in the United States was on the production of timber and fiber products. Foresters practiced "good" silviculture to produce fast growing, healthy stands of commercially valuable trees. As forest managers, we were concerned with the rapid establishment of regeneration, maintaining fully-stocked stands, harvesting schedules, and timber stand improvement activities (TSI). Research was directed to the development of silvicultural techniques to improve growth and species composition; genetic improvement for superior trees; more accurate predictions of growth and yield; and tree growth responses to cultural treatments. Non-commodity values were considered by research and management, but frequently only to the degree that they did not conflict with timber production objectives.

However, the environmental movements of the 1960s and '70s together with the passage of the National Forest Management Act in 1976 signaled our growing awareness of human impacts on the environment, and the importance of managing forests--especially public lands--for purposes other than timber. Public interest in the environment has now reached a high point with

larger, more diverse population taking an active role in planning the nagement, use, and protection of "their" forest resource.

These social factors together with new scientific information and man- ement activities lead to a philosophy and attitude that we can manage rests to sustain their full array of values and uses, that is, the "New rspectives" approach to managing natural resources. "New Perspectives" s become a generic term calling for changes in the traditional ways of naging resources; it is an attitude, an approach, and a philosophy about w we carry out multiple-use land and resource management. To me "New rspectives" is environmentally responsible resource management. Al- ough it had its beginnings in the early '60s with the conservation move- nt, it was not until the late 1980s that this need for environmental re- onsibility received serious public recognition through Jerry Franklin's omotion of "New Forestry."

In response to this demand for change, Dale Robertson, Chief of the rest Service, called for **New Perspectives in Managing the National Forest stem** as a special effort to use this new philosophy to change how the rest Service manages public lands and how we respond to people's needs d desires. **Developing an Ecological Perspective for Managing Forests** is a iority research program we are developing in response to this unique allenge and opportunity. The concept of "New Perspectives" is closely igned with our "Strategy for the '90s" and the need to better understand osystems, people and natural resource relationships, and resource tions.

Strategy for The '90s for USDA Forest Service Research

There are three dominant social trends affecting future protection, nagement, and use of natural resources and the content and conduct of our search programs. First is the expanding world population and associated mographic changes. Second is the increasing competition for the many es of natural resources--people are demanding more products and services om our finite resource base. And, third is the high standard of living st of us now enjoy--we can afford this environmental ethic. These trends ve resulted in an increasing public awareness and concern for natural re- urces and for national and global environmental issues. In addition to e traditional products--timber, big game animals, fish and water--society now interested in: how forests and climate affect each other; loss of ological diversity including T&E species; growing demand for wood and od fiber; preservation of "pristine" forests or old-growth; sustainable od production integrated with protection of non-commodity values; and intenance of forest health--nationally and globally.

In response to these trends and public concern for the environment and tural resources we developed, **Strategy for the '90s for USDA Forest Ser- ce Research**--a product of an intensive assessment of our mission, re- arch programs, organization, trends, and partnerships.

We defined the Forest Service Research Mission as: "To serve societ by developing and communicating the scientific information and technolog needed to protect, manage, and use the natural resources of forested an range lands." This mission encompasses a broad spectrum of responsibilities ranging from the basic and highly technical to the applied and on-the-ground technology transfer.

Based on our mission, goals, trends, and research capabilities, we hav divided our program into three major components with associated areas o emphasis under each. These components encompass the five critical area for research in the National Research Council's report, "Forestry Research A Mandate for Change."

These components of our Strategy can also be considered challenges t the forestry research community nationally and globally. They are:

Understanding Ecosystems-- Forest Service Research will focus on understanding the structure and function of forest ecosystems. We will take an ecosystem approach to our research with emphasis on sustained productivity, biological diversity, forest health, and the influence of global change. In a recent interview, Jack Ward Thomas, Chairperson of the Interagency Science Committee on the Role of the Spotted Owl, said "at long last we have gotten off our hands and knees to look at the entire landscape. It is almost mind-wrenching, it is such a tremendous shift in thinking. Even the body politic has learned it is a bigger question than an individual species. What about the system that supports them all? We are talking about ecosystems." The results of this research on understanding ecosystems will provide the scientific basis for realizing the full productivity of natural systems and resolving issues related to environmental concerns.

Understanding People and Natural Resource Relationships-- We will increase our emphasis on understanding how people perceive and value the management, use, and protection of our natural resource. Research will address socioeconomic factors that are closely associated with rural development and diversification, and international trade. This component reflects our recognition of people's needs and attitudes with regard to traditional uses of the forest resource.

Understanding and Expanding Resource Options-- The goal of this research component is to determine which protection and management practices, and utilization systems are most suitable for the production and use of natural resources. Findings will help us develop solutions to problems associated with competing uses of our forests for timber, water, wildlife, and other forest products as well as ecological values such as biological diversity. Research will include extension of the timber resource through better utilization and recycling.

This strategy is our blueprint for the 1990s. It is closely aligne with the 1990 Resources Planning Act (RPA) Program and was developed i concert with our university, industry, Federal and State partners. Wit implementation of this strategy, I believe that we can attain the vision I have for Forest Service Research. That vision is to be:

- Acknowledged by our customers and partners as a visible, effective, reliable, and objective source of useful scientific and technical information.

- Recognized nationally and internationally as a leader and advocate for scientifically-based natural resource management, use, and policymaking.

- Viewed as a workplace characterized by diversity, excitement, purpose, fairness, trust, challenge, reward, and opportunity for employees to contribute, succeed, and grow.

e used this vision in the preparation of our strategic plan for the 1990s.

Opportunities for Silviculture in The 1990s

Advances in silviculture in the 1990s and beyond require that we: (1) everse the downward trend in funding and staffing for silviculture both in esearch and practice; (2) develop stronger linkages between researchers id managers in all disciplines; (3) play a much larger role than we have ı the past on forest lands that are not dedicated primarily to timber oduction; and (4) not ignore past management experience and research reılts in developing future silviculture prescriptions and management alernatives for a large array of commodities, uses, and ecological values ıch as biological diversity and sustained productivity.

Frankly, the opportunities for all of you in the field of silviculture ould not be greater than they are right now. Science is never static. It ıst address the relevant issues of the day. The sands are shifting toward ore environmental awareness. We have the opportunity to surf on the same de that is reshaping the beach--or we can be washed along or away-- beıuse the beach will change in spite of us.

Since this is the "first" Biennial Southern Sivicultural Research Conerence" of the '90s, I think that the time is ripe to make a commitment or this decade and beyond. That commitment is to join the Forest Service ı:

- Expanding our understanding of forest and grassland ecosystems

- Examining how people use and value natural resources

- Increasing our understanding of the array of natural resource options and expanding resource productivity, potential, sustainability, and use.

Let us work together to develop the information and technology needed sustain multiple-resource values and practice multiple-use management th greater environmental sensitivity.

THE OUACHITA NATIONAL FOREST STORY--NEW FORESTRY, SOUTHERN STYLE [1]

David W. Wilson and James M. Guldin [2]

Summary. The challenge of Federal land management in the 1990s is to define responsible environmentalism in the balanced and sustainable multiple-use management of the forest. This is highlighted by the New Perspectives program of the USDA Forest Service, which brings environmental sensitivity and greater social acceptance into natural resource management and administration. On the Ouachita National Forest, recent planning activities, public challenges, and administrative response resulted in the inexorable conclusion that clearcutting is the most controversial and divisive management issue facing National Forest managers. Future management decisions on the Ouachita NF will be related to ecosystem sustainability under alternative silvicultural regimes. An immediate corollary to this is the development of a strong research partnership under New Perspectives that will evaluate the silvicultural and multi-resource sustainability of the proposed alternative silvicultural systems. Thus, the Ouachita NF story represents a beginning of a new perspective in forest stewardship into the 21st century.

Introduction

The concept of government forest reserves is certainly not unique in the world. Forestry has long been associated with either families or institutions that have held the reins of governance in society. However, Federal forestry in the United States is unique in being established as a result of a series of social events at the beginning of the 20th century; excessive lumbering, tax delinquency, unsuitability for agriculture, and physical remoteness of forested and deforested lands created a vast land base having great existing and potential value. Because enhanced wealth of America did not depend on the immediate exploitation of these reserves, our government had the luxury of being able to invest time and effort in the growth potential of these forest reserves, whose management would yield, according to the lofty principles promoted by Gifford Pinchot, the greatest good for the greatest number in the long run.

Challenges to Federal Land Management in The 1990s

Today, the domain of the USDA Forest Service encompasses over 191 million acres of public lands. The agency is charged with both protecting and managing this bounty of natural resources. The challenge for

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Deputy Forest Supervisor, Ouachita National Forest, Hot Springs, AR; and Associate Professor of Silviculture, Dept. Forest Resources, Univ. Arkansas, Monticello.

e 1990s is to produce these valuable goods and resources while preserving e ecological integrity of the resource base.

Several Forest Service officials have described the challenges. For ample, at the 19th International Union of Forestry Research Organiza-ons, the keynote address by George Leonard, the Associate Chief of the DA Forest Service, identified three challenges for management of Federal nds: (1) to better understand ecosystems; (2) to better understand the mplex relationship between people and natural resources; and (3) to bet-r understand and expand resource management options (Leonard 1990).

Secondly, the 1990 Resources Planning Act, the report of the Forest rvice to Congress, defined a program of multiple-use balance. It ad-cated environmentally-acceptable management practices including reduc-ons in clearcutting when alternative reproduction cutting methods would rk, and further addressed both biological diversity and old-growth. Dale bertson, Chief of the Forest Service, views this RPA report as the long-rm strategic plan of the organization, and considers the challenge as one defining responsible environmentalism as the balanced and sustainable ltiple use management of the forest.

Chief Robertson has also established a new initiative within the Forest rvice called "New Perspectives," and formed a Washington Office staff and rection to head up the initiative. Regions, Forests, and Experiment Sta-ons have followed suit. The charge of this initiative is to bring envi-nmental sensitivity and greater social acceptance into natural resource nagement and administration.

Perhaps most significant to the Ouachita National Forest and the South-n Region, the Chief and Senator David Pryor, (D-AR) took a "walk in the ods" on the Ouachita NF in August 1990, and their mutual agreement re-lted in the elimination of clearcutting as a routine reproduction cutting thod on the Ouachita. The agreement was captured by the Regional For-ter as Amendment No. 7 to the Ouachita NF Land and Resource Management an, and provides for clearcutting as a reproduction cutting method only der certain narrowly--defined silvicultural conditions-- such as insect disease attack, salvage of natural disturbance, and rehabilitation of derproductive, newly-acquired areas. But in April 1991, the Secretary of riculture rescinded Amendment 7; thus, the status of clearcutting still mains unresolved. Despite this, the Ouachita NF is committed to finding ternatives to claercutting. In recognition of this commitment, the Oua-ita NF has been designated a "Lead Forest" under the New Perspectives ogram. As such, the actions on the Ouachita NF could affect the future rection of silviculture and management on National Forest lands across e nation.

The Ouachita NF Story

The Ouachita NF is located in the Ouachita Mountains, an east-west in-rior highland formation located in west-central Arkansas and eastern Ok-homa. The Forest was established in 1907, making it the oldest National

Forest in Region 8. It is also the largest, at 1.6 million acres. Shortleaf pine (Pinus echinata Mill.), the most broadly-distributed and most poorly-understood of the major southern pines, reaches its ecological optimum in the Ouachitas, forming virtually pure stands over extensive areas, and encompassing mixed pine-hardwood stands over an even broader area (Critchfield and Little 1966; Little 1971; McWilliams et al., 1986). Smith (1986) commented that the Ouachita Mountains originally contained the largest shortleaf pine forest in the world, encompassing 5,000 mi^2 of the 11,000-mi^2 area of the Ouachitas. Further, because of its relatively slow growth rates, shortleaf pine from the Ouachitas is prized as lumber of exceptional quality.

In the mid-1960s, the Ouachita NF shifted management strategies from uneven-aged selective cutting to even-aged plantation management. Concurrently, in 1969, Weyerhaeuser Company bought the holdings of the Dierks family, totalling 1.8 million ac of uneven-aged forest lands, 90 percent of which was within the Ouachita Mountains. Weyerhaeuser immediately began an ambitious program of clearcutting existing forest, and replanting genetically-improved loblolly pine (Pinus taeda L.). Thus, within only a few years, the prevailing management in the Ouachita Mountains on both public and private forest lands shifted from uneven-aged selective cutting to clearcutting and planting. By the mid-1980s, the Ouachita NF was producing roughly 200 million bf/yr, through clearcutting, intensive site preparation (a combination of burning, herbicide application, ripping), and planting improved shortleaf pine--a practice similar, though somewhat less intensive, to that being conducted on the adjacent Weyerhaeuser lands.

In 1986, the Ouachita NF released its new Forest Plan, which called for a continuation of this management emphasis on timber production using almost exclusively clearcutting. Immediately, over twenty organizations formed different conservation coalitions, representing a four-state area, and filed six appeals at the Forest Plan. Concurrently, appeals of plans in California that failed to consider uneven-aged silviculture, as was the case with most plans across the country, were upheld.

The sudden complexity of the appeal situation on the Ouachita resulted in a supplemental analysis of the environmental impacts of the plan which included a host of alternatives. During this period of supplemental analysis in 1987, the Oklahoma congressional delegation engineered the passage of a bill declaring a rather sizable portion of the National Forest in Oklahoma as a National Recreation Area. This bill was significant in that it provided prescriptive language for the management of 98,000 ac of National Forest land, upon which the option for use of clearcutting was essentially eliminated.

In this environment, the Amended Draft of the Ouachita NF management plan was released, which recommended reducing clearcutting from 15,000 to 5,000 ac annually, increased use of even-aged natural regeneration methods such as seed tree and shelterwood from 0 to 5,000 ac annually, and imposed 15,000 ac annually of uneven-aged silviculture. This draft generated over 7,000 responses, split among those supporting a total shift to uneven-aged management with no herbicides, those advocating only even-aged management,

l those supporting the recommended alternative. Appeals began to be gen-ated for each timber sale. An Arkansas congressman submitted a bill to e the entire Forest a National Recreation Area. A lawsuit was filed to p all even-aged reproduction cutting methods, including seed tree and lterwood which were labelled, respectively, as "two-step clearcutting" l "three-step clearcutting." Timber volume harvested dropped to below) million bf annually; only through the graces of a short-term enhanced ierals program was the Ouachita NF able to prevent 25 percent county pay-its from plummeting.

Through this contentious social and political environment, the supple-ital planning process was driven by three basic objectives to: (1) dev-p legitimacy for the process; (2) develop a reputation for listening; (3) demonstrate a willingness to be responsive. Attention to these nciples leads to the inexorable conclusion: clearcutting is the most troversial and divisive management issue facing National Forest man-rs. Prior to the "walk in the woods," clearcutting was already being sed out on the Ouachita NF by the new decision-making environment on the tricts and in the Supervisor's Office. The refinement of the use of earcutting along the lines suggested by Amendment 7, coupled with im-ding resolution of outstanding lawsuits, will hopefully break the logjam management decision-making and will enable the final implementation of Forest Plan. Thus, silviculturally, the next decisions facing the chita NF are those related to ecosystem sustainability under alternative vicultural systems.

Research Challenges on The Ouachita NF

The critical challenge for ecosystem sustainability facing the Ouachita under the New Perspectives program is in the silviculture used to regen-te and develop the desired future condition of the forest. A major step to identify what the desired future condition will be, and this has not been accomplished. However, it will probably vary, depending on man-ment objectives for particular stands. On upper south- and west-facing pes, for example, the desired future condition might be an even-aged urally-regenerated stand dominated by pine and maintained by fire. On er north- and east-facing slopes, the desired stand might be an uneven-d mixed-species stand dominated by hardwoods such as southern red oak ercus falcata Michx. var. falcata) and white oak (Quercus alba L.). All sible gradations, from even-aged mixed pine-hardwood and hardwood stands uneven-aged pure pine and mixed pine-hardwood stands, will probably play ole in recreating the natural biodiversity of the Ouachitas.

The Ouachita NF is currently in the process of establishing a Citizens' isory Committee. This committee will be comprised of from eight to ten ple who are recognized by their peers as 'subject matter experts' and represent a diversity of views. Their charge is to assist the Forest describing the desired future condition.

These questions will be studied through the initiation of a two-stage earch program that makes an initial effort to quantify the broad limits

of natural regeneration establishment and development obtained under varying kinds of even-aged and uneven-aged reproduction cutting methods. In Phase I of the research program, over the next 2 years, plans are to configure the overstory to specific residual basal areas in both the pine and hardwood components, and to monitor regeneration of both pines and hardwoods that occurs under each system. The purpose of this research is to begin to formulate a crude predictive model for regeneration establishment. Phase II of the study will be imposed from years 2-10 of the 10-year planning horizon, and will monitor the development of established regeneration (both pines and hardwoods) under varying levels and tactics of release from competition (pines and/or hardwoods), including assessment of mechanical treatments as well as chemical treatment. This will allow the expansion of the predictive model to encompass stand development as well.

Natural regeneration can become established and develop beneath seed-tree and shelterwood reproduction cutting methods (Lawson and Kitchens 1983, Lawson 1986), though the effect of increasing residual mixed pine-hardwood overstory basal areas on regeneration establishment and development is poorly understood. Some combinations of residual overstory, such as those that retain high levels of both pines and hardwoods, might result in a different proportion of established pine seedlings and hardwood sapling development than that found under a pure pine seed-tree stand. Quantification of establishment and development of these conditions is essential to ensure the perpetuation of even-aged natural stands in the Ouachitas.

The real challenge in the Ouachitas will be to establish and develop natural regeneration of appropriate species composition in uneven-aged stands (Lawson 1986). This is complicated by the desirability of shortleaf pine, which is intolerant of shade (Fowells 1965), and the shaded conditions promoted by single-tree selection, the reproduction cutting method advocated by some of the conservation coalition members.

Uneven-aged silviculture has a proven record of success in Arkansas, based on over 40 years of experience at the Crossett Experimental Forest, in loblolly-shortleaf pine stands on the Upper Coastal Plain of the west Gulf region (Reynolds 1959, 1969; Reynolds et al., 1984). Some have argued that this experience justifies practicing the method in pure shortleaf pine stands in the Ouachita Mountains, despite the differences in forest type, physiography, and climate. Furthermore, the prescriptions at Crossett included control of nontarget hardwoods, initially by repeated cutting and subsequently with herbicides, roughly every 10 years. The nontarget control aspect, especially the use of herbicides, is a prescription component that is omitted by those who advocate translation of the system to shortleaf pine in the Ouachitas. On the other hand, there is some evidence of empirical success with uneven-aged silviculture in shortleaf pine, based on the evidence that the Dierks family used the method successfully. Another industry in the state is currently successfully using uneven-aged silviculture for shortleaf pine in the Ouachitas--though with herbicides as an element of the standard prescription.

The research question, then, from the uneven-aged perspective is not much different from that under the even-aged perspective. Studies in Phase I will document the establishment of both pine and hardwood regeneration beneath uneven-aged stands with varying residual stand structure of both

nes and hardwoods. This will be implemented using three patterns of im-ementation of uneven-aged stand structure--single-tree selection, group lection (where there is no residual stand within the groups), and a new riant of group selection where a residual stand of seed-tree or shelter-od density is retained within the group. Phase II will document the velopment of established regeneration within this overall study design.

As these studies mature, the operational imposition of natural regen-ation silviculture using both even-aged and uneven-aged methods will con-nue on the Ouachita NF. Additional research will look at related aspects these alternative silvicultural systems:

- water quality
- effects on small mammals, birds such as neotropical migrants, and larger species such as deer, turkey, and bear
- biodiversity implications
- logging costs and road system requirements
- fundamental aspects of silvics and natural regeneration biology
- visual quality.

sults from these and other studies will allow the Ouachita NF to better et its stated objectives of responsible environmentalism through balanced d sustainable multiple-use forestry.

Conclusions

The public expects National Forest land to be different and something ecial, full of big trees, with components of old growth, and featuring novative and nonindustrial approaches to management. The public expects voice in the design of alternatives and in the making of decisions. They pect pristine aquatic systems, aesthetically-pleasing recreational exper-nces, and a management philosophy that parallels and promotes a rich di-rsity of natural ecosystems. The opportunity to address these public lues through management and research represents a once-in-a-career op-rtunity for Federal land and resource managers, and for the forestry search community. A major rethinking of how to manage natural resources response to public values is clearly required. To this end, the Ouach-a NF story does not represent the end--but rather the beginning of a new rspective in forest stewardship for the 21st century.

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RESEARCH FOR NONINDUSTRIAL PRIVATE FOREST LANDOWNERS: THE SOUTH'S OPPORTUNITY [1]

Michael A. Webb [2]

Summary. Significant contributions of forestry to the South's economy are sketched. Changing forest demographics present new challenges to foresters, in educating, working with, and meeting the needs of the nonindustrial private forest landowners. Areas where particular attention could be focused are provided.

Introduction

One of the frustrations for uthern forestry in recent years s been the heavy criticism coming om a few small groups, such that en we in forestry forget the sigficance our work means to the uth. Yet quite literally, foresy has been the South's opportunity r many years. When thinking of e South's agricultural economy, ople tend to think of row crops: tton, soybeans, and tobacco, lite realizing timber produces more come than all others combined ig. 1). Yet, Forestry goes much rther. It also provided the base r our leading industry, already ntributing over $80 billion anally and one in every nine manucturing job to the South's economy ource: American Forest Council, 1250 Connecticut Avenue, Washington, D.C.).

It is important to recognize what foresters already contribute to the South as we continue to enhance the productivity of more and more of the region's forest lands through better management. This in turn, provides the resource to attract and sustain a larger forest products industry.

The key to tapping this potential however, is more complex, as it is based upon educating, working with, and meeting the needs of the South's one million plus, nonindustrial private forest (NIPF) landowners who own some 66 percent of the South's commercial forest lands. Unfortunately, the NIPF lands are producing at no greater than 50 percent of their productivity potential (DuBois et al., 1991). Within this NIPF productivity gap lies a tremendous opportunity.

To take advantage of this potential, the forestry community must: (1) learn how to work with these private forest landowners so we can help them manage their forests to meet their personal needs and goals in such a way that the resource is better utilized; (2)

Paper presented at Sixth Biennial uthern Silvicultural Research Conrence, Memphis, TN, Oct. 30-Nov. 1990.

President, Webb Forestry Consults, Columbia. Presenting serving Southern Director for the Assoc. Consulting Foresters and as Edir to <u>The Consultant</u>, the ACF urnal.

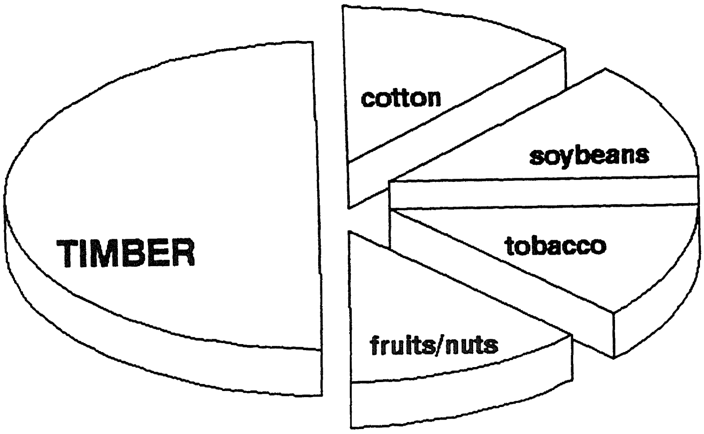

Figure 1. Forestry retains its position as the South's 'Top Agricul-tural Crop'.

develop management techniques that will protect the environment in order prevent undue government regulations that would inhibit reasonable, scie tifically-based utilization of the resources to meet all our needs.

To accomplish these, however, we need your help. When I say 'We', I referring to the field foresters, i.e., state foresters, consultants, e tension foresters, and industry foresters responsible for working with t NIPF.

Our problem is that on the one hand, most of us are mentally geared t ward pine plantations and the tremendous gains in productivity availab from the research success of genetic improved stock, brush and herbaceo weed control, etc. On the other, the timberlands we are called on manage are 94 percent in natural stands (Fig. 2). Further, there is like to be little change from this situation as many private landowners pref not to clearcut and/or go to the expense of intensive reforestation.

To give some background for this, we need to look at a general profi of the NIPF landowner.[1] Generally, he/she is approximately 59-60 yea old, retired, or nearing retirement. Their woodland averages only abo 80 ac, and aesthetics and recreation are the highest priority uses f their ownership. Carrying an evaluation of goals further, stewardsh and/or caring for the land as a heritage to pass along to further gener tions is second and timber production is third.

Given this profile of NIPF landowners and their general prioritie there are several reasons why they do not do more clearcutting and/ artificial regeneration. These include the unattractiveness of clearcuts

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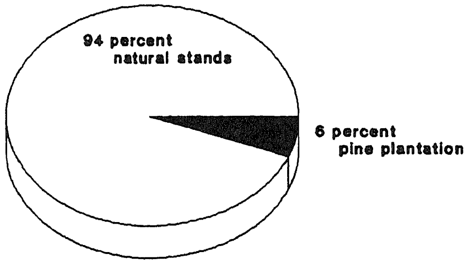
[1] A summary of research conducted by Dr. Jacqueline Haymond and Sarah Bal win at Clemson University, and by Larry Dolittle at Mississippi Sta University.

atural stands vs. artificial stands
creage breakdown



**gure 2. Ratio of nonindustrial pri-
ate forest land ownership vs. artific-
al stands.**

the high taxes often associated with a significant increase in income, the high reforestation costs, and the desire for a better cash flow during their lifetimes. Simply put, for many landowners a clearcut and replant--which will not produce significant additional income for 20 years or more--does not fit as well into their lifestyles or needs.

While this does not mean that NIPF landowners will not do any clearcutting and reforestation. They will; particu-
arly where there is a reasonable justification, such as for stands that
e particularly overmature, offsite, unproductive, or in severe danger due
insect or disease. It does mean that we need to find and evaluate other
anagement options that will allow us to maintain stands in a healthy, pro-
ctive condition, balancing aesthetic concerns with the need to utilize
at productivity as well.

By example, interesting management alternatives for meeting some of
PF needs seem to be within the work of Russ Reynolds and James Baker at
e Crosset Farm forestry forties. Their studies show good stands of lob-
lly pine timber could grow 400-500 bd ft/ac/yr even up to the age of 60
70 years old (Reynolds et al., 1989). Select cutting every 5 years on
is basis would produce from 2 to 2.5 thousand bd ft/ac, worth $400-500
c. This kind of periodic income can be much more interesting to a person
sixty as it still leaves an attractive forest for the future while pro-
ding substantial regular income without the high income tax and heavy re-
restation expense.

The Role of Forest Research

Again, I emphasize we need your help. If the South is to capitalize on
e productive potential of the NIPF resource, then silviculture research
needed to: (1) Focus on how we can better protect, enhance, and utilize
e existing NIPF resource; (2) Find a better means to transfer the accumu-
tive knowledge of forest resource to the field forester.

Specifically, there seem to be several areas of research needed to take
tter advantage of the existing NIPF resource.

1. Growth, yield, and economic analysis for natural stands and mixed stands. As management entails an expense, we need a better understanding of the productivity of natural stands in order to evaluate management alternatives and returns.

2. Selective logging technology to allow selective cutting. We need to be able to do it more cost-effectively, with less damage to the residual stands.

3. Identify preharvest stand improvements to reduce future site preparation costs for artificial regeneration, or encourage natural regeneration (e.g., prescribed burning, weed and brush control, etc.).

4. Ecological and holistic studies (i.e., analyzing the impact of manipulation of the forest on the entire forest community).

5. Growth and enhancement techniques for natural stands.

6. Forest protection. This is absolutely critical to private landowners and also one of the best means for reaching them about the importance of good forestry.

7. Identification of the regeneration mechanism of the different species to allow more natural regeneration.

8. New and less expensive regeneration alternatives such as artificial and mixed stands: i.e., regeneration relying both on planting and natural regeneration, such as utilizing spot chemical treatment for site preparation, then plant fewer pine trees/ac and let the sweetgums, oak, and other hardwoods come up outside the treated spots along with the pine. The first few thinnings would, of course, be mostly of low-grade hardwood pulpwood, but you will still have your major value trees within your pine stems.

Passing on The Torch

As more research is done and added to historical research, we need a better mechanism of passing this accumulated knowledge on the field foresters. At present, there are essentially only two generally known sources of continuing education for field foresters: Southern Journal of Applied Forestry and educational seminars.

While the Southern Journal of Applied Forestry carries many excellent research papers, they tend to focus on artificial regeneration and to reflect new research, which by its very nature is very site-specific and has not necessarily been repeated to determine its validity. Therefore, its applicability is generally limited. By example, the November 1989 issue was randomly chosen: of its ten articles, six dealt with some facet of pine plantation establishment or management. Only one dealt with the silviculture of natural stands.

Seminars and symposiums are very valuable, but they are also very expensive and time consuming to attend. Even a 3-day seminar can cost from \$1-\$2 thousand in expenses and lost time. While seminars will continue to

ill a critical role for continuing education, field foresters need publiations and articles that reflect accumulative knowledge as well as historcal research that is still applicable.

An excellent example is an article on forest fertilization by H. Lee llen in the Journal of Forestry (Allen 1987). He gave an excellent overiew of the results of years of research; provided basic information, a reiew of the present opportunities, and where a forester can find out more pecific information for application in his area. Through articles such as hese, field foresters can recognize possible management opportunities and hen look further into the research.

Another example of a very good, educational source is the proceedings f a symposium, such as those recently published for the Symposium on The anagement of Longleaf Pine, held at Long Beach, Mississippi, in 1989 (Farar 1990). It gave an excellent overview of the full management implicaions and silvicultural techniques necessary for longleaf pine. This type ublication is critically important as proceedings not only bring out new esearch, but also the appropriate historical research which may have been one years before, is still valid, but would not normally be republished. ummary articles in forestry journals referring to proceedings can also rovide an excellent overview for field foresters, thereby leading them to he entire volume for more in-depth study.

There is no question, development of the NIPF resource has to be one of he greatest single opportunities for the South today. It is literally an pportunity to 'Have our cake and eat it too'. We cannot only have our eautiful southern forests into perpetuity, but also broaden our forest inustrial base that is so critical for the future economic well-being of the outh.

Two basic keys to this opportunity are to develop and utilize management techniques that take advantage of the existing resource at the same ime that they are better adapted to the needs of the NIPF owners. The key o this is to keep the foresters responsible updated on the developments of he field.

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INITIAL PROSPECTS FOR NATURAL REGENERATION OF PINE IN COASTAL SOUTH CAROLINA AFTER HURRICANE HUGO [1]

Earle P. Jones, Jr., David L. Bramlett and Earl R. Sluder [2]

Abstract. In Spring 1990, 6 months after Hurricane Hugo struck, permanent observation plots were established to assess pine regeneration potential on the Francis Marion National Forest and the Santee Experimental Forest, in coastal South Carolina. Plots were located in loblolly (_Pinus taeda_ L.) and longleaf pine (_P. palustris_ Mill.) stands where timber had been salvaged by skidder, horse, or helicopter, or had not been salvaged. Pre-Hugo stand conditions were determined on ¼-acre plots by measuring residual trees, stumps, and other debris. Smaller sample plots were used to estimate frequency and coverage of competing vegetation, including hardwood species, shrubs, vines, grasses and herbs. Pine seedlings were counted on 10 milacre plots on each ¼-ac plot, and classed by ages of <1, 1, or >1 year. Initial results describe the effects of Hugo and the different methods of salvage logging on the advance pine regeneration. Preliminary review of the data shows a paucity of longleaf pine regeneration, but there are plenty of loblolly pine seedlings, even from the 1989-90 crop, on some sites. Development of hardwood and shrub competition under more open stand conditions will be an important factor in the success of pine regeneration. These data will provide baseline information to document the establishment of pine regeneration, and subsequent measurements will assess the actual pine component of growing stock over the next 2 decades.

Introduction

Hurricane Hugo was perhaps the worst storm to hit the east coast of the United States this century. Besides doing tremendous damage to homes, utilities, and other man-made objects, it devastated forest resources in the coastal plain of South Carolina. An estimated 4 million acres of forest were damaged in 23 counties of South Carolina, with severest damage in seven counties (Fig. 1).

The brunt of the storm was felt on the 250,000-ac Francis Marion National Forest (FMNF), located north of Charleston immediately inland of the coastal marshes. Hugo roared ashore on the evening and morning of September 21-22, 1989, with windspeeds that exceeded 135 mph.

Prior to Hugo, the FMNF had some of the finest loblolly (_Pinus taeda_ L.) and longleaf (_P. palustris_ Mill.) pine timber in the Southeast, and many acres of prime hardwoods

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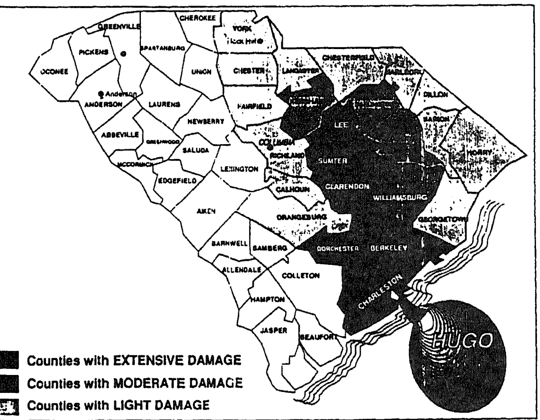
[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Research Forester, Project Leader, and Research Forester, Southeastern Forest Exp. Sta., Dry Branch, GA.



igure 1. South Carolina counties amaged by Hurricane Hugo. Study rea is in the southern-most corner f Berkeley County, SC (Source: SC orestry Commission).

growing on wetlands. It supported the largest concentration of the endangered red-cockaded woodpeckers (Picoides borealis Vieillot) (RCW) in the world. The RCW lost about 87 percent of their cavity trees to the hurricane (USDA Forest Service 1990). On the FMNF, much of the timber 9 inches dbh and larger was broken off, uprooted, or left leaning, and it was not uncommon for pine trees 24 inches and larger to be broken off or uprooted. Most of the large pine trees left standing suffered a high degree of crown breakage, thereby hampering the seed production for at least a couple of years.

The pine and hardwood debris was 1 to 4 ft deep on the forest floor and obviously would lessen prospects for replacement seedling atches. Uprooted trees left root mats protruding above the litter. However, blowdown was not uniform across the National Forest and some stands ad a few pines remaining, perhaps enough for an eventual seed tree or ight shelterwood stand. Immediate National Forest plans were to salvage s much wood as possible, but to leave standing trees with less than a 45-egree lean as potential seed sources and RCW foraging and nesting sites.

Objectives

The objectives of our research are to observe and document the effects f this major hurricane on the ecology of pine forest types. Of particular nterest is how the heavy debris and the rapid increase in competing speies will affect the establishment and growth of existing and new seedling rops. This paper describes the data collection process and some initial bservations and comparisons.

Methods

Study plots were installed during February-May 1990, 6-9 months after he hurricane, on the Witherbee Ranger District and the Santee Experimental orest in the southern-most corner of Berkeley County, South Carolina (Fig.). Sample stands represented different methods of logging used to salvage oblolly and longleaf pine sawlogs (Table 1). Five longleaf and three loblly pine stands were selected. Longleaf is a highly desirable species or timber products, RCW habitat, and aesthetic values, and the post-Hugo egeneration will be critical for the maintenance of this species on the MNF. The initial plan was to have 20 sample points in each stand, but

Table 1. Regeneration plots installed, by species and salvage method.

Species	No salvage	Horse	Skidder	Helicopter	Total
	(number)				
Loblolly	10	–	10	10	30
Longleaf	--	6	35	10	51
Total	10	6	45	20	81

difficult working conditions forced us to reduce the goal to 10 per stand Three stands were sampled in the longleaf-skidder category: one had 1 plots, one had 10 plots, and one was large enough for only six plots. Loggers used horses to supplement skidder logging during extremely wet periods, therefore, there were not many areas where effects of horse logging alone could be observed.

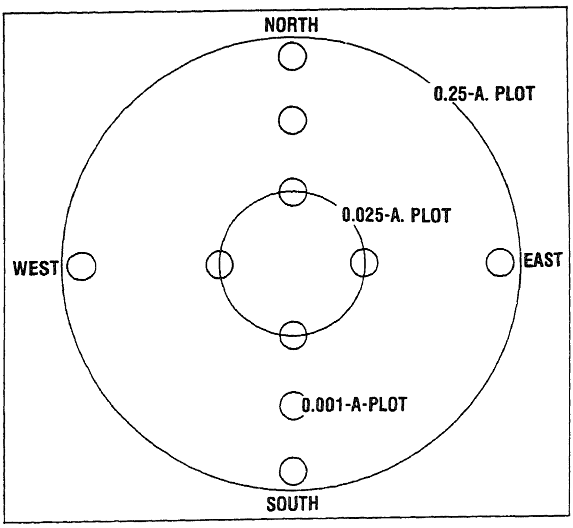


Figure 2. Arrangement of sample plots located at each sample point. Plot radii are: 0.25-ac plot, 58.88 ft; 0.025-ac plot, 18.62 ft; and 0.001-ac plot, 3.72 ft.

Sampling points were partiall randomized within each stand. The were located with respect to a baseline along some recognizable feature such as a tram road. The baseline was divided into a numbe of equal-length segments to provide the planned number of sampling points, and turning points were randomly located within each segment. From each turning point a perpendicular bearing and random distance were taken on each side of the baseline to determine the sampling point.

At each sampling point three sizes of plots were installed (Fig. 2): a 0.25-ac plot was used to measure trees larger than 4.5 inches dbh; a concentric 0.025-ac plot was used to count trees taller than 4.5 ft, but less than 4.6 inches dbh; and ten 1-milacre subplots within the 0.25-ac plot were used to sample ground cover and vegetation less than or equal to 4.5 ft tall. Data from the 0.025-ac plots are not included in this report. In the field, all plot centers were marked with treated wooden stakes which were labeled and flagged conspicuously.

rter-acre Plots

All trees larger than 4.5 inches dbh on the 0.25-ac plots were re-ded. Trees were identified as loblolly, longleaf, or shortleaf (P. ech-ta Mill.) pines, oaks (Quercus spp.), sweetgum (Liquidambar styraciflua , black gum (Nyssa sylvatica Marsh.), and other hardwoods. Each tree assigned to a condition class after Hugo: standing tree, stem broken, ged in another tree, or a stump left after salvage. The estimated ght of stem breakage also was recorded. Dbh was measured to the nearest inch on all standing and down trees, regardless of condition; stump di-ter was measured for salvaged trees. Percent root damage and degree of n from vertical were estimated. Thus, a tree recorded as having 100 cent root damage and 90 degree lean was uprooted and laying on the und. Total height of standing trees was visually estimated as vertical ght of terminal above the ground. Thus, a 60-ft-long stem with severe n may have been tallied as 30 ft tall. Crown class before Hugo and the cent of residual crown after Hugo were estimated.

acre Plots

Vegetation and ground cover less than or equal to 4.5 ft tall were pled on milacre plots. These plots were established in a prescribed, form pattern on each 0.25-ac plot (Fig. 2). They were carefully treated avoid damage by trampling during measurement. Since rapid estimates of cent coverage by various vegetation classes is subject to some personal s, virtually all of these estimates were made by a single experienced hnician.

Without disturbing the milacre, the percent coverage of non-pine vege-ion was estimated in five broad categories: herbaceous (forbs and leg-s other than grass), grasses, shrubs, vines, and overtopping hardwoods. cent coverage of debris on the milacre was estimated for heavy (3 inches meter and larger) and light material, and each of these was categorized either suspended or on-the-ground debris. Of course, most of the debris a result of Hugo, but no attempt was made to quantify the proportion. percentage of exposed soil was estimated. Since milacre coverage in se several categories may be layered, their sum may exceed 100 percent.

Loblolly and longleaf pine seedlings less than or equal to 4.5 ft tall e counted if they could be found without much disturbance to the debris vegetation on the milacre. Seedlings were recorded in three age ups: those germinated in 1988 or earlier (>1 yr old), germinated in 1989 yr old), or germinated in 1990 (<1 yr old). The 1990 germinants were umed to be from the seed crop that was mature in the fall of 1989, and t ready to be cast when Hugo hit in September.

The best pine seedling on each milacre was selected and marked with a e flag. Another seedling was taken at random and marked with a red g, and if seven or more seedlings were present, a second random seedling marked with a green flag. For each selected seedling, a detailed rec- was made including: age (as described above), vertical height to the rest 0.1 ft in whatever posture the seedling was found, and up to 4 dling conditions (such as healthy, free-to-grow, bent, under debris, ken, weak, and overtopped by hardwood).

Data from field tally sheets were transferred to computer files verified. SAS procedures (SAS Institute 1987) were used to summarize analyze the data. Published equations (McClure 1968) were used to conv stump measurements to dbh before Hugo.

Table 2. Stock and stand data before (reconstructed) and after Hurricane Hugo, and percentage of original basal area residual after Hugo by stand and salvage method.

Salvage method	Before (reconstructed) Trees/ ac	Basal area	Average dbh	After Trees/ ac	Basal area	Pct BA residual
	no.	ft²/ac	inch	no.	ft²/ac	percent
Loblolly pine stands						
No salvage	168	106	10.7	54	19	18
Skidder	56	80	16.3	3	1.4	2
Helicopter	139	107	11.9	27	12	11
Longleaf pine stands						
Horse	54	63	14.7	7	9	14
Skidder	52	54	13.8	5	4	7
	80	67	12.4	20	10	15
	65	65	13.5	13	10	15
Helicopter	128	102	12.0	77	53	52

[1] Percent basal area residual = basal area after Hugo ÷ before Hugo.

Results And Discussion

The 0.25-ac plot data indicate stand conditions prior to and imme ately after Hugo (Table 2). These observations establish baseline from which stand recovery will be measured. Stocking prior to the s probably was underestimated because some stumps were hidden under the h debris. It was surprising that the stand where no timber was salvaged only 106 ft² of basal area before Hugo, even though it had not been cu more than 30 years. Although the mean dbh before Hugo in that stand only 10.7 inches, some trees were up to 27 inches dbh They were the gest tree diameters of any of the eight stands surveyed. One of the l leaf stands salvaged by skidder had the lowest stocking of 52 trees/ac 54 ft² of basal area before Hugo. That stand had recently been thinned

Residual trees were classed as standing if their lean was less tha degrees and root damage was less than 10 percent. It was impossibl closely estimate root damage unless the tree was obviously uprooted.

dual basal area as a percent of that before Hugo (Table 2) reflects the nt of overall damage. The relatively high 18 percent of original basal remaining after Hugo on the "no salvage" stand is due to the fact that eaners were cut. A high of 52 percent residual for longleaf-helicopter cates that this type logging was least destructive.

3. Mean milacre plot coverage by components of low vegetation, overtopping hardwoods, large (over 3 diameter) and small debris, suspended and on the ground, and bare soil, by stand and salvage .

ly pine stands

e	Low vegetation					Overtop.	Large debris		Small debris		Total	Bare
	Herbs	Grass	Shrubs	Vines	Total	hdwd.	Susp.	Ground	Susp.	Ground	debris	soil
	(percent)											
vage	1	1	5	2	9	43	5	1	28	99	133	< 1
r	1	11	5	1	18	2	2	4	9	72	86	27
	< 1	16	8	2	26	22	8	3	34	98	144	1
af pine stands												
	17	11	23	< 1	52	1	3	1	11	90	104	9
r	< 1	2	5	< 1	7	< 1	1	2	3	57	63	42
	1	3	18	< 1	23	6	3	4	8	77	92	22
	3	11	6	0	20	< 1	2	1	12	77	91	22
pter	2	11	47	< 1	60	10	4	2	15	98	120	< 1

Competition will increase dramatically in the next few years as veg-ion fills in the openings created by Hugo. Milacre plot data provide line estimates of competition for the pine seedling crop at the be-ing of the first response year (Table 3). Grasses were the most prom-t species in the loblolly stands, while shrubs were most prominent on leaf sites. Vines were few in all cases. The high totals for low-ing vegetation on helicopter- and horse-logged stands indicate that e methods did considerably less site damage than did skidder logging.

Pine seedlings must also compete with Hugo debris on the site. Small is on the ground, mostly pine and hardwood leaves and twigs, constitute greatest problem for the new seedlings (Table 3). It is interesting large debris (over 3 inches in diameter) has a rather small impact on microsite, averaging no more than 8 percent coverage in any stand. r skidding did a much better job of reducing total debris loading than e and helicopter logging did. By the same token, skidders exposed much bare soil, which is more favorable for pine seed germination.

The advance pine seedlings from 1989 and earlier are the most reliable ion of the new seedlings for stand recovery (Table 4), both in the lob-y and longleaf pine stands. When these measurements were made in the

spring of 1990, new 1990 germinants were very sparse for loblolly and e tirely absent for longleaf. One exception is the 4,200 loblolly seedlin on the loblolly skidder site. This stand is the closest to the coast, a was perhaps the most severely damaged by Hugo, of the eight stands sample But cones were mature, and the extensive salvage of the stand with skidde exposed bare soil and distributed unopened cones while moving the tr tops. The aggressive nature of loblolly pine is demonstrated by the lar number of its seedlings in longleaf stands. There were virtually no lon leaf seedlings in loblolly stands. In the stands sampled, it appears th the advance regeneration from the 1989 and older germinations of both sp cies may be enough to maintain the areas as pine type, barring losses competition.

Table 4. Pine seedling density, separated by species and year of germination, by stand and salvage method.

Salvage method	Loblolly seedlings 1988+	Loblolly seedlings 1989	Loblolly seedlings 88-90	Loblolly seedlings 1990	Longleaf seedlings 1988+	Longleaf seedlings 1989	Longleaf seedlings 88-90	Longleaf seedlings 1990	Both 88-89
	(number/ac)								
Loblolly pine stands									
No salvage	1,610	730	2,340	10	10	0	10	0	2,350
Skidder	700	370	1,070	4,200	0	0	0	0	1,070
Helicopter	3,300	1,280	4,580	180	0	0	0	0	4,458
Longleaf pine stands									
Horse	450	17	467	50	5,633	0	5,633	0	6,100
Skidder	121	21	142	26	1,458	205	1,663	0	1,805
	2,690	320	3,010	0	8,110	30	8,140	0	11,150
	317	17	333	233	7,517	0	7,517	0	7,850
Helicopter	800	710	1,510	140	400	0	400	0	1,910

Percent milacre stocking is a more useful measure of regeneration su cess, especially if suppressed seedlings are excluded (Table 5). A milac stocking of 50 to 60 percent usually indicates successful regeneration, a looking at the "all pines" category (seedlings of any age or species), t percent milacre stocking values look very favorable in 5 of the 8 stan studied. However, if the free-to-grow standard is imposed, none would me the 50 percent success criterion. The impact of the 4,200 germinants/ for 1990 is again seen in the loblolly skidder stand. Because they we small, succulent, and at high risk at the time of observation, very few these germinants were considered free-to-grow. When discounts for growi condition and competition were imposed, the milacre stocking was reduc from 79 to 8 percent.

Table 5. Pine seedling milacre stocking, by stand and salvage method.

Salvage method	All pines	Free-to-grow, 88-89 Loblolly	Free-to-grow, 88-89 Longleaf
	(percent)		
Loblolly pine stands			
No salvage	43	0	0
Skidder	79	8 [1]	0
Helicopter	58	29	0
Longleaf pine stands			
Horse	45	0	8
Skidder	35	5	19
	66	14	43
	57	2	22
Helicopter	52	16	3

[1] Does not include the 1990 seedlings for which there were 61 percent milacre stocking, and 49 percent free-to-grow.

Table 6. Average height of "best seedling", by stand and salvage method.

Salvage method	Loblolly seedlings 1988+	Loblolly seedlings 1989	Loblolly seedlings 1990	Longleaf seedlings 1988+	Longleaf seedlings 1989	Longleaf seedlings 1990
	ft					
Loblolly pine stands						
No salvage	1.27	.31	.10	--	--	--
Skidder	.81	.40	.12	--	--	--
Helicopter	.69	.35	.12	--	--	--
Longleaf pine stands						
Horse	1.75	.10	.10	.12	--	--
Skidder	1.60	.30	.10	.21	.10	--
	.54	.40	--	.11	--	--
	.90	--	.10	.19	--	--
Helicopter	.60	.40	.20	.17	--	--

The advance regeneration seedlings growing under the cover of the p Hugo stand are not very tall (Table 6). Average heights of the "be seedlings are no more than 1.75 ft for loblolly pine, and 0.21 ft longleaf. The tallest longleaf seedling observed was only 1.8 ft tall.

Conclusion

Our initial data on the recovery of the Hugo-damaged pine stands representative of the Francis Marion National Forest. It will be intere ing to follow remeasurements of these stands, and to compare the devel ment of advance pine regeneration and future seed crops with the devel ment of the competing species. We would expect to see a gradual breakd of the debris left from Hugo, and the different logging operations certa ly had different effects on the microsite. The next seed crop in respo to Hugo "release" should be expected in October of 1992. We have alre begun an assessment of cone crop and crown recovery on these plots. 1990, midsummer shoot development on the crowns was considerably beh what is normally expected for that point in the season, perhaps a result root wrenching.

For operational forestry in Hugo-damaged stands, a wait-and-see p scription may be best for most natural loblolly pine stands. Prospects natural longleaf pine stands are not good. They may require careful tre ments, including artificial regeneration to reestablish the species.

Acknowledgment

The authors wish to acknowledge the assistance of John DuPre and W Harms in locating study areas on the Witherbee District and Santee Expe mental Forest, respectively.

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INFLUENCE OF NURSERY FERTILIZATION, SITE QUALITY, AND WEED CONTROL ON FIRST-YEAR PERFORMANCE OF OUTPLANTED LOBLOLLY PINE [1]

Brad L. Barber, J. Suzanne Messina, Johannes P. van Buijtenen, and Margot M. Wall [2]

Abstract. Loblolly pine (Pinus taeda L.) seedlings grown in the nursery under various pre- and post-sown nitrogen fertilization regimes were outplanted on a poor site and a good site in east Texas, and several herbaceous weed control treatments were compared. Post-sowing fertilization significantly increased survival on the poor site but had little effect on the good site. Pre-sowing fertilization had little effect on survival at both sites. Post-sowing fertilization had a positive impact on first-year size of the seedlings; however, use of initial seedling size as a covariate reduced statistical significance in most cases. Weed control greatly improved first-year performance of seedlings on the poor site but only slightly improved performance on the good site.

Introduction

Survival of planted pines is ost critical during the first growng season. If seedlings can establish their root systems soon after lanting and can survive that first eason, they will likely grow to be part of the future stand, at least ntil interspecific competition sets n or until thinning occurs. Seveal strategies exist for increasing irst-year survival of planted ines. Among these include planting ood quality seedlings and controling weeds around the seedlings.

Nitrogen (N) is often added to nursery soils to produce better quality bare-root seedlings (Davey 1983, May 1985). Additions are made either before seedbed preparation or during seedling development. When N is added during development, top dressings are usually made in several equal increments. However, recent data show N additions made at increasing increments that follow the development of seedlings may produce better quality seedlings (Timmer and Armstrong 1987; Brissette et al., 1989).

In addition to planting quality seedlings, herbaceous weed control has proven effective in increasing both survival and growth of newly planted pines (Nelson et al., 1981; Metcalf 1986; Zutter et al., 1986; Creighton et al., 1987; Mitchell et al., 1988; Schoenholtz and Barber 1989). By decreasing the competition for soil moisture, planted seedlings are given the opportunity to establish their root systems before the commonly experienced dry periods occur in summer.

Paper presented at Sixth Biennial outhern Silvicultural Research Conerence, Memphis, TN, Oct. 30-Nov. , 1990.

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The study described here was an extension of another study done whe the effects of various N fertilization regimes in the nursery were invest gated in relation to seedling quality. Seedlings produced in the nurse study were outplanted on a poor and a good site in east Texas. This pap reports first-year field performance of these seedlings with and witho weed control.

Methods

Nursery Fertilization

As part of another study, improved loblolly pine (Pinus taeda L.) see lings were grown under various nitrogen fertilization regimes at Texas Fo est Service's Indian Mound Nursery near Alto in Cherokee County. The so at the nursery is an Amite/Iuka/Bibb sandy clay loam. Seed were sown 12 April 1989. Seedbed density was 290 seedlings/m^2.

Nitrogen (ammonium nitrate) was applied using one of three methods: (Pre-sown –; before seedbed preparation; (2) Equal post-sown –; duri growth in five equal increments; (3) Exponential post-sown –; during grow in five exponentially-increasing increments. Pre-sown levels were 0, 2 45, and 90 kg/ha (Table 1). In addition, pre-sown treatment plots we top-dressed with 30 kg/ha in August. Total seasonal levels for equ post-sown treatments were 0, 84, 168, 336 kg/ha. The exponential post-sc treatment was 168 kg/ha applied as 5.4, 10.8, 21.5, 43.0, and 86.0 kg/ increments. Post-sown top dressings were done every 3 weeks beginning weeks after sowing.

Table 1. Nitrogen fertilization regimes.

Method	Before seedbed preparation	Weeks after sowing 6	9	12	15	18	Total seasonal rate
	(kg/ha)						
Pre-sown	0	–	–	–	–	30	30
"	22	–	–	–	–	30	52
"	45	–	–	–	–	30	75
"	90	–	–	–	–	30	120
Equal post-sown	–	0	0	0	0	0	0
"	–	17	17	17	17	17	84
"	–	34	34	34	34	34	168
"	–	67	67	67	67	67	336
Exponential post-sown	–	5	11	22	43	86	168

Treatments were arranged in a randomized complete block design with ree blocks. Pre-sown plots were 1.2 x 6.1 m and post-sown plots were 1.2 2.4 m. Pre-sown treatments were applied to one bed while post-sown eatments were were applied to an adjacent bed. Therefore, pre- and post-wn treatments were treated as separate experiments.

udy Areas

Seedlings were outplanted on two open land areas in east Texas having ffering site quality. One area, considered a poor site, is located in derson County (Fig. 1). The soil on this site was a Darco fine sand hav-g a site index at 50 years of 21 m for loblolly pine. The other area is nsidered a good site and is located in Upshur County. The soil on this te is a Bowie fine sandy loam having a site index of 26 m.

Vegetation on the poor site included soft golden aster [Heterotheca pi-sa (Nutt.) Shinners], sunflower (Helianthus annuus L.), snakecotton roelichia floridana (Nutt.) Moq.], slender goldenweed [Croptilon divari-tum (Nutt.) Raf.], purple sandgrass [Triplasis purpurea (Walt.) Chapm.], olly croton (Croton capitatus Michx.), partridge pea (Cassia fascicula- Michx.), horseweed [Conyza canadensis (L.) Cronq.], threeawn [Aristada smantha Trin. & Rupr.), sandbur (Cenchrus incertus M.A. Curtis), slender abgrass [Digitaria filiformis (L.) Koel.], rough buttonweed (Diodia ter- Walt.), trailing wildbean [Strophολytes helvola (L.) Ell.], ragweed (Am-osia artimissifolia L.), and bullnettle [Cnidoscolus texana (Muell. Arg.) all].

Vegetation on the good site included purpletop [Tridens flavus (L.) tchc.], wild-honeysuckle (Gaura filiformis Small), horseweed, partridge a, wooly croton, ragweed, bermudagrass [Cynodon dactylon (L.) Pers.], mphorweed (Heterotheca latifolia Buckl.), splitbeard bluestem (Andropogon rnarius Michx.), broomsedge (Andropogon virginicus L.), panicgrass (Pan-um spp.), paspalum (Paspalum spp.), dewberry (Rubus spp.), and late-owering eupatorium (Eupatorium serotinum Michx.).

ot Establishment

On each site, plots were laid out in three randomized complete blocks th respect to nursery fertilization regime. Blocking was such that seed-ngs occurring within a particular block in the nursery remained blocked gether in the field. Each plot contained 72 measurement seedlings. Buf- seedlings were also planted on the perimeter of each plot. Seedlings re planted at spacings of 1.5 x 1.8 and 1.8 x 2.7 m on the poor and good tes, respectively.

ed Control

Weed control was applied to half of each plot. Within the weed control de of each plot, a three by two factorial treatment structure was used nsisting of three herbicides or herbicide mixtures and two application tes. Treatments differed between the two sites. On the poor site where e soil was a fine sand, herbicide treatments were: (1) 0.21 kg ai/ha xazinone + 0.11 kg ai/ha sulfometuron methyl (12 oz/ac Velpar L™ plus 2 /ac Oust™); (2) 0.28 kg ai/ha hexazinone + 0.11 kg ai/ha sulfometuron thyl (16 oz/ac Velpar L plus 2 oz/ac Oust); (3) 0.16 kg ai/ha sulfomet-on methyl (3 oz/ac Oust). Applications were done on 14 April or 19 May.

On the good site where the soil was a fine sandy loam, herbicide treatments were: (1) 0.42 kg ai/ha hexazinone + 0.11 kg ai/ha sulfometuron methyl (24 oz/ac Velpar L plus 2 oz/ac Oust); (2) 0.16 kg ai/ha sulfometuron methyl (3 oz/ac Oust); (3) 0.28 kg ae/ha imazapyr (8 oz/ac Arsenal™ Applicators Concentrate). Applications were done on either 12 April or 16 May 1989. Herbicides were sprayed over-the-top of the seedlings in 0.9- x 0.9-m spots using a CP3 backpack sprayer equipped with an even-flat-fan nozzle.

Analyses

A split-plot experimental design was used where nursery fertilization regime served as whole plots and weed control served as subplots. Regression analysis was performed on the fertilization part of the study. Also, analyses of variance and covariance were used for comparing equal vs. exponential post-sown regimes (168 kg/ha).

For determining differences between the various weed control treatments, analysis of variance was conducted and treatment means were separated by Duncan's multiple range test. For these analyses, only six seedlings within the no weed control side of the plot (check) were used since each of the six herbicide x application date combinations contained only six seedlings per plot.

A volume index was calculated as the square of groundline diameter multiplied by total height. For analysis, arcsin transformation was used for survival data and logarithmic transformation was used for volume index.

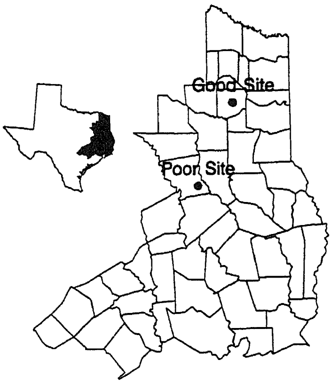
Results

Site Quality

Site quality had a significant impact on both survival and growth of the outplanted pines. Where no weed control was used, survival of the seedlings averaged 90 percent on the good site and 56 percent on the poor site (Fig. 2). A significant site x post-sown N interaction was evident for survival. On the good site, there was little difference in survival among the various post-sown N treatments. However, on the poor site, as these N fertilization levels increased, survival increased. Average first-year volume index of seedlings growing on the good site was more than double that for those growing on the poor site.

N Fertilization--Poor Site

As N fertilization during seedling development increased from 0 to 336 kg/ha, pine survival increased from 33 to between 60 and 70 percent where no weed control was used and from 78 to 92 percent where weeds were controlled (Fig. 3). Regression analysis revealed a significant positive linear effect of post-sown rate on survival (Table 2). Inclusion of initial diameter (as measured shortly after outplanting) as a covariate decreased the significance of this linear effect from $p = 0.0296$ to $p = 0.3141$. The exponential rate resulted in the greatest survival among the post-sown treatments. However, there was no significant difference in survival between the equal 168 kg/ha post-sown rate and the exponential 168 kg/ha post-sown rate, although both treatments resulted in significantly greater survival than the control.



igure 1. Locations of study sites.

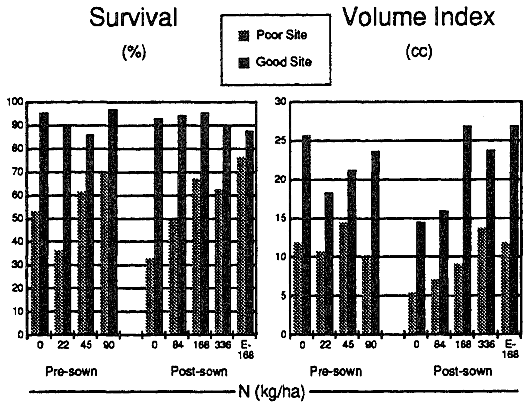


Figure 2. First-year survival and volume index of pines growing on both sites where weed control was not applied.

Table 2. Probabilities of a greater F value occurring (p values) as determined by regression analysis for linear effects and seedling parameters for the poor and good sites.

Parameter	Analysis[2]	Pre-sown fertilization			Post-sown Fertilization[1]		
		N rate	Weed control	Covariate	N rate	Weed control	Covariate
				Poor site			
ArcSurv1	1	0.4505	0.0001	-	0.0296	0.0001	-
	2	0.2355	0.0001	0.5563	0.3141	0.0001	0.3204
Ht1	1	0.0683	0.0014	-	0.0231	0.0004	-
	2	0.6142	0.0001	0.0007	0.0133	0.0003	0.1267
D1	1	0.3430	0.0001	-	0.0287	0.0001	-
	2	0.6075	0.0001	0.0338	0.3751	0.0001	0.0110
LogV1	1	0.3390	0.0001	-	0.0159	0.0002	-
	2	0.1662	0.0001	0.2714	0.1995	0.0001	0.2619
				Good site			
ArcSurv1	1	0.8904	0.4347	-	0.3578	0.3523	-
	2	0.5392	0.5179	0.3091	0.4018	0.3682	0.9672
Ht1	1	0.4004	0.1779	-	0.2051	0.0401	-
	2	0.6258	0.1302	0.0162	0.4272	0.0357	0.0051
D1	1	0.3552	0.0137	-	0.1457	0.0029	-
	2	0.5607	0.0114	0.3274	0.1830	0.0039	0.8585
LogV1	1	0.5369	0.0805	-	0.1500	0.1071	-
	2	0.7454	0.0681	0.2899	0.2658	0.0952	0.2513

[1] Post-sown analysis does not include exponentially-increasing treatment.
[2] Covariate inculded in analysis 2.

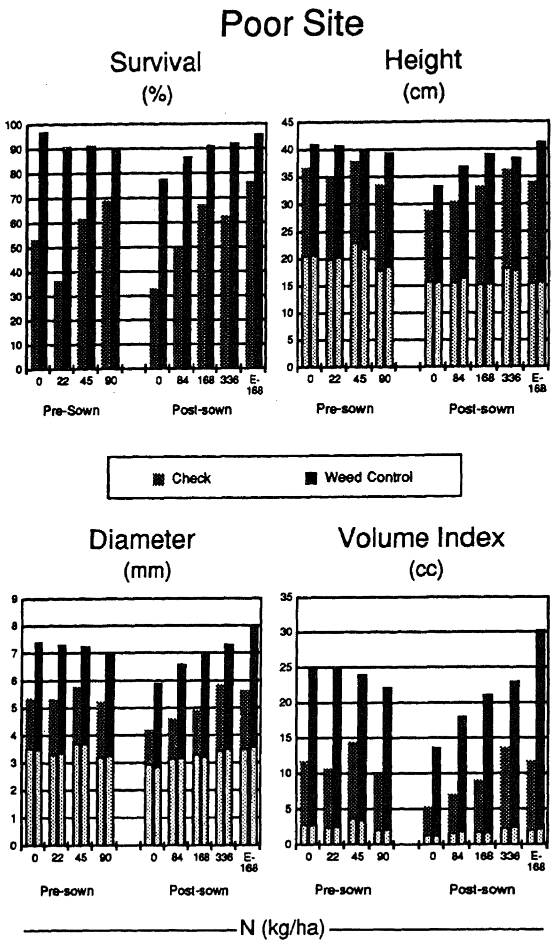


Figure 3. First-year survival, height, groundline diameter, and volume index of pines growing on the poor site for various nursery nitrogen fertilization regimes with and without weed control. Lower portion of each bar indicates values as measured shortly after outplanting.

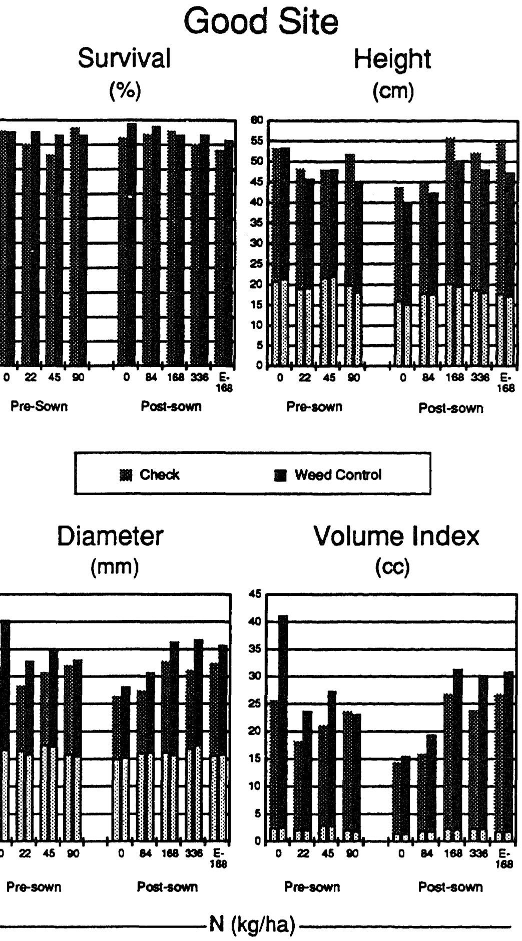
Although there appeared to b slight interaction between pre-s rate and weed control, no signi cant effect on survival occur for pre-sown fertilizer treatme (Table 2). Where weed control used, survival was greatest percent) for the 0 kg/ha N lev Where no herbicides were used, s vival generally increased with creasing rate.

First-year growth was signi cantly increased by post-sown N ditions (Table 2). However, m of the growth performance can attributed to initial size of seedlings. Although no signific effects were found for initial v ues, when these values were inc ded as covariates (initial diame for first-year diameter, init height for first-year height, initial volume index for first-y volume index) significance lev for linear effects dropped dram ically for diameter and volume dex. Significance actually creased for height when init values were accounted for. The fore, post-sown N additions in nursery increased first-year hei of outplanted pines beyond t which can be attributed to init height. While seedlings grown der exponentially increasing N crements in the nursery were lar after one growing season in field than those grown under same total amount of seasonal N plied in equal increments, the d ferences were not statistica significant.

Addition of pre-sown N had no significant effect (p = 0.05) on eit initial or first-year size parameters of the seedlings. However, there appear to be a slight negative trend with increasing pre-sown N rates. deed, at the p = 0.0683 level, height declined with increasing pre-s rates.

Nitrogen Fertilization--Good Site

Survival was excellent for all N levels regardless of whether we



gure 4. First-year survival, ight, groundline diameter, and lume index of pines growing on e good site for various nursery trogen fertilization regimes with d without weed control. Lower rtion of each bar indicates in- ial values as measured shortly ter outplanting.

were controlled (Fig. 4). There was no significant effect on survival of N fertilization in the nursery for either pre- or post-sown treatments (Table 2). Survival ranged from a low of 86 percent for 45 kg/ha pre-sown N with no weed control to 98 percent for 0 kg/ha post-sown N with weed control.

Although not significant, there did appear to be a slight reduction in survival as post-sown N level increased, especially where weeds were not controlled.

There were no significant linear effects of post-sown N additions on first-year height, diameter, or volume index although values for all three size parameters increased with increasing post-sown N. The 168 and 336 kg/ha equal-increment additions and the 168 kg/ha exponential-increment addition resulted in approximately 25, 25, and 80 percent greater height, diameter, and volume index, respectively, than was shown for the 0 kg/ha rate. There was very little difference in size of first-year seedlings between equal and exponentially-increasing post-sown fertilization regimes.

No significant effects were detected among pre-sown N additions for any size parameter. However, as occurred on the poor site, the largest seedlings after one growing season in the field were those grown where no pre-sown nitrogen was added.

<u>ed Control--Poor Site</u>

Pines responded dramatically to chemical weed control. Both survival d size of the seedlings after the first growing season were very sig- ficantly (p = 0.0001) greater for seedlings growing where weeds were con- olled than those where weeds were not controlled (Fig. 5). Survival ere weeds were controlled varied from 84 to 95 percent compared with only percent for check plots. There were no significant differences in

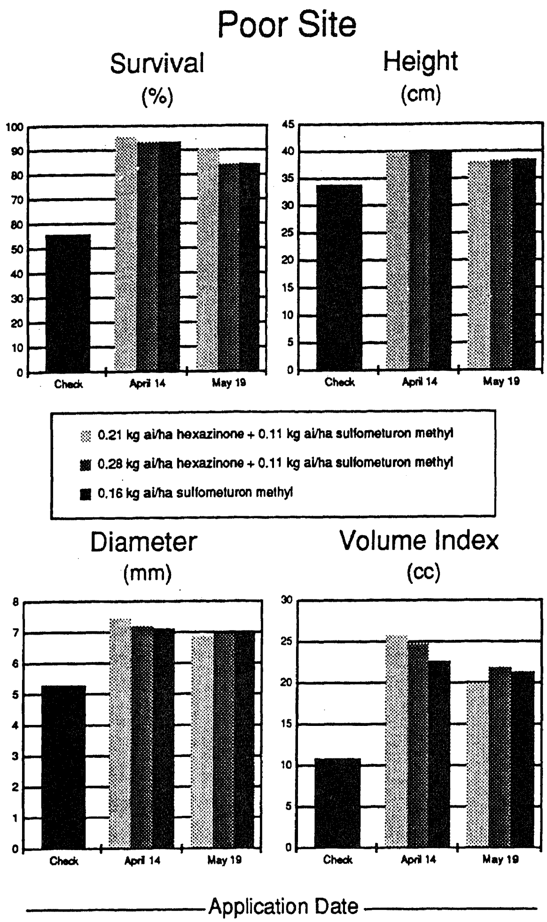


Figure 5. First-year survival, height, groundline diameter, and volume index of pines growing on the poor site for various weed control treatments.

survival among the three herbicid mixtures. However, significantl more pines survived where herbici des were sprayed in April than i May.

No significant differences wer detected in height, diameter, an volume index among the three herbi cide treatments or between the tw application dates. Pines responde most to 0.21 kg ai/ha hexazinone 0.11 kg ai/ha sulfometuron methy applied in April. This weed con trol treatment resulted in 18 per cent taller seedlings and 41 per cent greater diameter than chec seedlings. Volume index, which i more indicative of crown size, wa 136 percent greater for this treat ment than for the check.

Weed Control--Good Site

Weed control did not signifi cantly increase survival althoug survival on check plots was lowe than for any of the weed contro treatments. Survival for chec plot seedlings was 91 percent whil survival for weed control treat ments ranged from 92 to 96 percen (Fig. 6).

Pines responded much less t weed control on the good site tha on the poor site. Significant dif ferences (p = 0.05) occurred amon the herbicide mixtures (Table 3) Imazapyr stunted the seedlings Height of imazapyr-treated seedlings at the end of the first growing seaso was only 73 percent that of check seedlings. Diameter for imazapyr-treate seedlings was no different from check seedlings. Greatest growth respons was obtained with 0.42 kg ai/ha hexazinone + 0.11 kg ai/ha sulfometuro methyl. Although height was only 6 percent greater than check plot seed lings for this treatment, diameter and volume index were 25 and 72 percen greater, respectively.

A herbicide mixture x application date interaction occurred. April ap plication of 0.42 kg ai/ha hexazinone + 0.11 kg ai/ha resulted in signifi cantly larger pines than May application (Table 3).

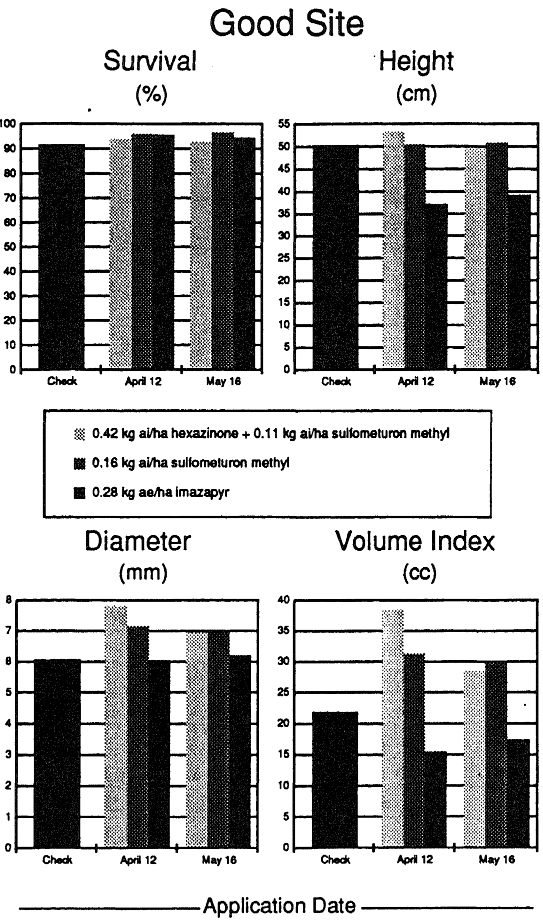


Figure 6. First-year survival, height, groundline diameter, and volume index of pines growing on the good site for various weed control treatments.

Discussion

Applying N during development of seedlings in the nursery increased survival on the poor site and growth on both sites. Much of the first-year performance could be attributed to the initial size of the seedlings-- the bigger the seedling produced in the nursery, the better the performance in the field. On the poor site, there was a definite positive correlation between seedling size and survival. Perhaps fertilization increased the potential for root growth by increasing the size of the seedlings or increasing the tissue N concentration, or both. This greater potential may have allowed fertilized seedlings to become established sooner and thus survive and grow better. On the good site, where moisture and probably nutrients were not as lacking, survival was excellent for all nursery fertilization regimes.

On the poor site, top dressings applied in exponentially increasing increments resulted in better 1st-year performance than when the fertilizer was added in equal increments in the nursery. Timmer and Armstrong (1987) attributed the increased yield obtained from exponential additions to improved nutrition of seedlings when supplied with nutrients at rates matching the varying demands of the plant. On the good site, however, the equal increment regime gave slightly better results.

Applying N before the seed was sown did not result in better first-year performance. In fact, there appeared to be a slight negative effect (although not statistically significant) with increasing pre-sown levels. The reason for this is not known. Applying fertilizer before seed germination may have had a toxic or inhibiting effect on early seedling development in the nursery. Even applying just 22 kg/ha appeared to be detrimental to first-year performance.

Table 3. Results from Duncan's New Multiple Range Test for various weed control treatments used at the good site (Fig. 6.) Treatment factor levels having common letters are not significantly different (p= 0.05).

Factor level	Ht1	D1	LogV1
0.42 kg ai/ha hexazinone + 0.11 kg ai/ha sulfometurol methyl	A	A	A
0.16 kg ai/ha sulfometuron methyl	A	B	A
0.28 kg ae/ha imazapyr	B	C	C
Check	A	C	B
0.42 kg ai/ha hexazinone + 0.11 kg ai/ha sulfometurol methyl			
April 12	A	A	A
May 16	B	B	B

Weed control benefitted seedlings most on the poor site. All weed control treatments significantly increased both survival and growth of seedlings on the poor site. The best herbicide mixture was 0.21 kg ai/ha hexazinone + 0.11 kg ai/ha sulfometuron methyl (12 oz/ac Velpar L + 2 oz/a Oust). This mixture not only resulted in greatest survival and growth, bu is also the least expensive treatment used. Very low rates of hexazinon are needed on dry sandy soils--higher rates may result in damage to th seedlings.

Pines responded much less to weed control on the good site than on th poor site. East Texas received good rainfall throughout spring and earl summer in 1989. Perhaps if 1989 had been dryer, relative performance o seedlings receiving weed control would have been better than those growin where weeds were not controlled. Although there was no detrimental effec on survival, imazapyr at 0.28 kg ae/ha (8 oz/ac Arsenal) significantl stunted the seedlings. The product label calls for 6 to 10 oz/ac. Possibly, lower rates may provide adequate weed control without significantl stunting seedlings.

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THREE-YEAR FIELD COMPARISON OF NATURAL LOBLOLLY PINE REGENERATION WITH IMPROVED CONTAINER STOCK [1]

Michael D. Cain and James P. Barnett [2]

Abstract. A field study compared genetically improved, container-grown loblolly pine (Pinus taeda L.) seedlings with naturally established loblolly seedlings on a cutover pine site in southern Arkansas. Pines on 50 percent of all plots were annually released from woody and herbaceous competition within a 2-ft radius. After 3 years, release treatments resulted in statistically significant growth gains and better survival for pines in both regeneration techniques. Mean differences between planted and naturally seeded pines were not as great as those achieved by competition control.

Introduction

About 75 percent of the loblolly pine (Pinus taeda L.) acreage in the South originated from natural seedfall, and this regeneration method remains important for perpetuating the species as a commercial resource. By using seedtree, shelterwood, selection, or patch clearcut methods, landowners can regenerate pine sites by natural seeding. The advantages of natural regeneration include lower establishment cost, less labor and heavy equipment, better early root system development, and no problems with geographic origin of seed if previous generations were natural to the area.

There are also disadvantage natural regeneration compared artificial techniques. One quently cited disadvantage is lack of genetic improvement. Re estimates from tree improvement grams indicate that volume gains be as much as 12 percent for lob ly pine at 25 years of age (1988). However, this disadvan can be somewhat reconciled by l ing the best pines as seed produ so that their progeny will be w adapted to the site (Zobel Talbert 1984).

According to Zobel and Tal (1984), it is unrealistic to as that improved trees can be pla in aggressive competing vegeta with little care and still grow standingly. Yet, many forest l owners desire low-cost regenera alternatives that may necessi outplanting or seeding in less optimum site conditions. Theref information is needed on the gr potential of improved pine seedl compared with natural pine rege ation when both are established lowing minimal site preparat

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Container-grown seedlings were used in the present study because they provide an efficient use of genetically improved seed, are quickly produced, and have an extended planting season (Barnett and Brissette 1986; Elliott 1986).

Materials And Methods

Study Area

The study was initiated in a 5-ac clearcut on the Crossett Experimental Forest, Ashley County, Arkansas. Soil is a Bude silt loam (Glossaquic Fragiudalf), and the site index is 85-90 ft at 50 years for loblolly pine.

The clearcut was made in summer 1985 to salvage approximately 11,000 fbm/ac (Doyle) of pine sawlogs that were infested and killed by southern pine beetles (Dendroctonus frontalis Zimmermann). In April 1986, the clearcut was treated with hexazinone (Velpar™L) at the rate of 3 lb a.i. /ac using herbicide spotguns on a 3- by 3-ft grid to control nonpine vegetation. A few residual hardwoods taller than 6 ft and not killed by Velpar were injected with a 50-percent solution of glyphosate (Roundup™) in summer 1987.

Study Installation and Treatments

Twelve plots of 0.2 ac each with subplots of 0.09-ac were established in the clearcut to accommodate 121 planting spots on a 9- by 9-ft spacing. Two establishment techniques--planting container-grown seedlings and natural regeneration--were randomly assigned to each of six plots. On three planted plots and on three naturally seeded plots, the measurement pines were released from overtopping woody and herbaceous competition during the growing season for 3 consecutive years.

Loblolly pine seeds for the container stock were obtained from the Kisatchie National Forest Seed Orchard near Pollock, Louisiana, but the original clone selections were from a northern Louisiana area. The open-pollinated seeds were from a mixed orchard lot that had been collected in 1984 before the orchard was rouged, and had an expected genetic gain of about 5 percent over nursery-run stock. The seeds were stratified 45 days before sowing on September 18, 1986.

Seedlings were grown in Ray Leach Stubby Cells™ filled with a 1:1 peat-vermiculite medium. Greenhouse cultural treatments followed the guidelines described by Barnett and Brissette (1986). Because the seedlings were grown during the winter months, development was slow and the stock was about 26 weeks old when planted. Container-grown seedlings were outplanted on April 2, 1987. Shoot length averaged 0.38 ft and groundline diameter (gld) averaged 0.1 inch. Because the recommended height of container-grown loblolly seedlings is 0.5 to 0.7 ft at the time of outplanting (Barnett and Brissette 1986), the seedlings used in this study could be considered small. Nevertheless, they had a distinct height advantage compared with the natural regeneration that had just begun to germinate from seed.

Natural pine regeneration seeded onto all 12 plots from the 1986-87 (fall through spring) seedcrop. That seedcrop averaged over 300 thousand seeds/ac, with 75 percent judged as potentially viable. For comparison, an average seedyear for loblolly pine is expected to produce from 30 thousand to 80 thousand viable seeds/ac. In early summer 1987, 49 of the natural seedlings were selected as measurement trees on each of the six interior subplots designated to monitor the growth of natural pine regeneration. Their selection was based on seedling quality and spacing. The tallest 1st-year seedlings were most often chosen if their terminal bud was intact; however, other quality criteria included the presence of dark green needles and the absence of insects or disease.

On the six release plots, woody vegetation was hand-cut within a 2-ft radius of preselected pines, and herbaceous vegetation was controlled with sulfometuron methyl (Oust™) and glyphosate (Roundup) within the same 2-ft radius. Oust was the principal herbicide because of pine tolerance and was applied at 3.75 oz a.i./ac; Roundup was applied at 0.68 lb a.i./ac. The herbicides were dispersed as water solutions at the rate of 11 gal/ac using backpack sprayers, and pines were shielded at the time of treatment. During the first growing season, only one cutting treatment and one chemical treatment were used; but two cutting treatments and two chemical treatments were needed in both the second and third growing seasons. Roundup was included only in the 3rd year to control broomsedge (Andropogon virginicus L.), which is resistant to Oust. Any additional natural pine seedlings that became established within the 2-ft treatment radius were not eliminated during the first 3 years because they did not overtop the measurement pines.

Measurements and Data Analysis

After the 1st year of establishment, tree heights were measured to the nearest 0.1 ft, and gld's were measured to the nearest 0.04 inch on all survivors of the original 49 measurement pines per interior subplot. Using the same degree of accuracy, total heights and gld's were remeasured on all surviving measurement pines at the end of the third growing season. Volume index was calculated as (total height) x $(gld)^2$. The measurement pines on plots without release were judged as free-to-grow or overtopped, and the overtopping species were recorded. Natural pine and woody rootstock densities and milacre stocking were estimated from an inventory of 9 milacre-quadrats that were systematically established on each of the 12 interior subplots after the third growing season. The dominant (tallest) natural pine seedling on each milacre was judged as being free-to-grow or overtopped.

Analysis of variance for a completely randomized design was used to evaluate treatment effects on pine survival and overtopped condition. Growth and size of measured pines were subjected to analysis of covariance. Covariates were 1st-year height, 1st-year gld, and 1st-year volume when analyzing annual growth and 3rd-year means for total height, gld, and volume, respectively. Percent values for survival, milacre stocking, and free-to-grow condition were compared following arcsine transformation. Statistically significant differences were tested by orthogonal comparisons

as follows: Natural (N) vs. Natural/Release (N/R); Planted (P) vs. Planted/Release (P/R); and N + N/R vs. P + P/R. All analyses were carried out at the 0.05 level of significance.

Results And Discussion

Density and Milacre Stocking of Natural Pines and Woody Competition

Three years after establishment, natural pine density averaged over 9,000 seedlings/ac and ranged from 5,000 to more than 12,000 stems/ac (Table 1). Milacre stocking of those natural seedlings averaged 86 percent (Table 1) and was no less than 67 percent on any one plot. Although milacre stocking was optimum for naturally regenerated even-aged stands, density exceeded the more desirable range of between 1,000 and 5,000 stems /ac. Growth reduction from intraspecies competition can be expected at such high densities following crown closure, but natural thinning tends to moderate that competitive influence. For example, density of natural seedlings declined by an average of 3,000 trees/ac from the first through the third growing seasons.

Table 1. Condition of natural pine regeneration 3 years after establishment.

Treatment comparisons	Density	Milacre stocking[1]	Free-to-grow[2]
	(stems/ac)	(percent)	
Natural	12,407	89	51
Natural/release	8,185	89	86
Planted	10,629	82	36
Planted/release	5,148	85	66
N + N/R	10,296	89	69
P + P/R	7,888	84	51

[1] Based on the presence of at least one natural pine seedling per milacre and 9 systematically spaced milacres per 0.09-ac subplot.

[2] Percent of stocked milacres in which the tallest natural pine seedling was not overtopped by competing species.

Competition from nonpine species was more pervasive than pine competition after 3 years and was assessed by the proportion of stocked milacres in which the dominant natural pine seedlings were overtopped. Without release, only 36 percent of dominant natural seedlings on planted plots and 51 percent on natural plots were judged as free-to-grow after 3 years (Table 1). The release of individual measurement pines on the remaining six

plots tended to improve the overall free-to-grow condition of dominant natural seedlings on 66 to 86 percent of stocked milacres within planted/release and natural/release plots, respectively.

Four years after a broadcast herbicide treatment, woody nonpine species had an average density of over 4,000 rootstocks/ac and 96 percent milacre stocking. The principal woody competitor was American beautyberry (*Callicarpa americana* L.) which is not effectively controlled by hexazinone (McLemore 1983).

Pine Response to Treatments

Survival of measurement pines was directly related to control of competing vegetation. With release, survival averaged 97 percent for both natural and planted pine seedlings (Table 2). Without release, survival was reduced by 10 percent for natural pines and by 19 percent for planted pines. The latter mean difference was statistically significant when compared with planting plus release.

Table 2. Survival and overtopped condition of measurement pines 3 years after establishment.

Treatment comparisons	Survival	(PR>F)[1]	Overtopped status	(PR>F)
	(percent)		(percent)	
Natural	87	(0.057)	74 }	
Natural/release	97		--	}... (0.754)
Planted	78	(0.013)	79 }	
Planted/release	97		--	
N + N/R	92	(0.376)	--	
P + P/R	88		--	
Mean square error	53		64	

[1]The probability of obtaining a larger F-ratio under the null hypothesis.

On plots without release, from 74 to 79 percent of measurement pines were judged to be overtopped by competing vegetation on natural and planted plots, respectively, but the two regeneration methods showed no statistically significant difference (Table 2). American beautyberry and blackberry (*Rubus* spp.) were the predominant competitors, accounting for 67 percent of all overtopping species on natural pine plots and 59 percent on planted pine plots. Other frequently observed species that overtopped the

pines included flowering dogwood (Cornus florida L.), Japanese honeysuckle (Lonicera japonica Thunb.), red maple (Acer rubrum L.), and sassafras [Sassafras albidum (Nutt.) Nees].

Annual height growth of both natural and planted pine seedlings was improved by the release treatments. The mean difference in favor of release was 0.73 ft on natural pine plots and 0.95 ft on planted pine plots; the latter mean difference was statistically nonsignificant because of more variation among sample means (Table 3). As a result of competition control, mean increases in height over 3 years were 1.47 ft on natural pine plots and 1.88 ft on planted pine plots (Table 4). No significant difference was observed in annual height growth or in 3rd-year heights between the two regeneration techniques.

Table 3. Mean annual growth of surviving measurement pines during the previous 2 years.

Treatment comparisons	Growth[1] Height	(PR>F)[2]	Gld	(PR>F)	Volume	(PR>F)
	(ft)		(inch)		(ft^3)	
Natural	1.07	(0.003)	0.15	(0.001)	0.0037	(0.002)
Natural/release	1.80		0.38		0.0144	
Planted	1.03	(0.064)	0.17	(0.004)	0.0058	(0.001)
Planted/release	1.98		0.53		0.0382	
N + N/R	1.44	(0.895)	0.26	(0.616)	0.0090	(0.045)
P + P/R	1.51		0.35		0.0220	
Mean square error	0.022		0.001		0.693×10^{-5}	

[1] Means have been adjusted for 1st-year height, gld, and volume, respectively.

[2] The probability of obtaining a larger F-ratio under the null hypothesis.

Both natural pines and planted pines exhibited a positive and statistically significant gld growth response to release treatments (Table 3). The gain in gld growth from competition control was 0.23 inch/yr for natural pines and 0.36 inch/yr for planted pines. After 3 years, released pines were 0.46 inch larger in gld than untreated pines on naturally regenerated plots and 0.71 inch larger than untreated pines on planted plots (Table 4). There were no statistically significant differences in 3rd-year gld's or in annual gld growth for planted pines compared with natural pines when released and nonreleased plots were combined.

Table 4. **Mean size of surviving measurement pines 3 years after establishment.**

Treatment comparisons	3rd-year means[1] Total height	(PR>F)[2]	Gld	(PR>F)	Volume	(PR>F)
	(ft)		(inch)		(ft^3)	
Natural	2.90	(0.003)	0.43	(0.001)	0.0075	(0.002)
Natural/release	4.37		0.89		0.0290	
Planted	2.87	(0.068)	0.48	(0.004)	0.0119	(0.001)
Planted/release	4.75		1.19		0.0766)	
N + N/R	3.64	(0.877)	0.66	(0.601)	0.0182	(0.045)
P + P/R	3.81		0.84		0.0442	
Mean square error	0.091		0.005		0.278×10^{-4}	

[1] Means have been adjusted for 1st-year height, gld, and volume, respectively.

[2] The probability of obtaining a larger F-ratio under the null hypothesis.

Annual volume growth of the measurement pines was significantly improved by competition control and by the use of container-grown planting stock (Table 3). After 3 years, mean differences in volume per tree between release treatments averaged 0.022 ft^3 on natural pine plots and 0.065 ft^3 on planted pine plots, and those differences were statistically significant (Table 4). The mean difference between planted pines and natural pines averaged 0.026 ft^3, with a statistically significant advantage for planted pines. Had the container stock been of the morphological grade now recommended, the performance of the planted pines may have been improved even farther (Barnett 1991).

Release treatments in this study were designed to ensure that the pines would not be overtopped by competing vegetation during the first few years, which is why a treatment area of only 12.57 ft^2/tree was used. However, recent competition control research on these sites has shown that herbaceous vegetation reduces the growth of non-overtopped loblolly pines more than woody vegetation during the first 3 years after establishment (Cain 1988). The area of treatment can also be important. For example, Tiarks and Haywood (1981) found that slash pine (P. elliottii Engelm.) growth was linearly related to the increasing width of herbaceous plant control. As such, a better pine growth response could have been expected in the present study following an increase in the area of competition control.

Summary And Conclusions

Intensive competition control for 3 years within a 2-ft radius of measurement pines resulted in statistically significant growth gains and better survival for both naturally established seedlings and planted, container-grown seedlings. During that same period, planted pines achieved a statistically significant improvement in volume growth compared with natural seedlings. Nevertheless, mean differences between regeneration techniques were not as great as those achieved by competition control.

The data suggest that container-grown, genetically improved loblolly pines can be outplanted on areas with minimal site preparation and will equal or exceed the growth of naturally established pine regeneration, even though the container stock used in this study was of smaller size than is recommended for outplanting. To maximize survival, as well as growth potential of genetically improved planting stock, intensive control of both herbaceous and woody competition appears to be justified during the first few years after field establishment.

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EFFECT OF PESTICIDES AND NUMBER OF SEED PER SPOT ON SEEDLING ESTABLISHMENT FROM DIRECT-SOWN OCALA SAND PINE SEED [1]

Kenneth W. Outcalt [2]

Abstract. To improve spacing and conserve seed, the U.S. Forest Service began using the Bracke™ scarifier for regenerating Ocala sand pine [Pinus clausa var. clausa (D.B. Ward)] stands about 6 years ago. The objectives of this study were to (1) determine if seed treatment with pesticides was necessary to control seed predation, and (2) determine the number of seed to sow on each spot to obtain the desired level of stocking. Although some seed predation did occur, seed treatment with Arasan™ or Ropel™ did not significantly increase seedling establishment. And while the shading of seed spots did increase seedling establishment, it is likely not economically feasible. Increasing the number of seed from two to five per spot increased stocking by nearly three times: 23 vs. 63 percent. Doubling the number of seed to 10 gave no additional increase in stocking levels. Thus, if sown during the proper season, seed predation is not severe enough to justify the use of repellants, and five well-placed seed per spot is adequate for obtaining a well-stocked stand of Ocala sand pine.

Introduction

In the past most Ocala sand pine (Pinus clausa var. clausa D.B. Ward) stands harvested on the Ocala National Forest, Florida, were regenerated by chopping or chopping and burning, followed by broadcast seeding using 0.55-1.1 kg/ha of seed (Price 1973). Although this system was good, it was not entirely satisfactory. Many areas during years with extended drought periods, which occur about 3 years out of 10, failed to regenerate adequately. In good years with adequate rainfall, some areas became overstocked and required precommercial thinning to prevent stand stagnation. Additionally, there was no spacing control and the system was quite wasteful of seed, which increased the cost and reduced the area that could be regenerated with genetically-improved seed. To improve spacing, eliminate precommercial thinning, reduce costs, and conserve seed, managers on the Ocala National Forest began using the Bracke™ scarifier-seeder in the mid-1980s. This is an integrated method which combines site preparation and seeding into one operation. It was very successful the first year, but in subsequent seasons a significant number of areas failed to achieve adequate stocking.

It was suspected that seed predation was at least partially responsible for these failures because past work had shown it could and often is a substantial problem in artificial regeneration of Ocala sand pine stands by direct seeding.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Only 3 percent of unprotected, viable seed sown on test sites by Cooper et al. (1959) produced seedlings, while the rate was nearly 90 percent from protected seed. Similar results occurred when Ocala sand pine seed were sown on sandhill sites in northwest Florida (Burns and McReynolds 1975). In the past, severe seed predation was overcome by the use of various pesticides, but many effective formulations are no longer available, or because of environmental concerns land managers do not choose to use them. The objective of the first portion of this study was to determine if pesticides presently available for treating seed would be effective in reducing predation of Ocala sand pine seed on sites regenerated with the Bracke scarifier-seeder.

Because it deposits seed only on selected microsites (Van Damme 1988), the scarifier-seeder mechanism uses less seed than the broadcast system. The initial seeding rate was 0.3 kg/ha which was increased to 0.35 kg during the third sowing season. The actual amount of seed required for successful regeneration, however, was unknown. The objective of the second phase of this study was to determine the number of seed required per spot, or scalp, to give an adequate stocking without wasting valuable seed.

Methods

All study sites were on the Lake George district of the Ocala National Forest located in central Florida. Specific sites were chosen at random from sand pine sites regenerated with the scarifier-seeder equipment during the 1986 season, spanning November 1986 to February 1987. These mechanisms are equipped with rotating teeth, which turn over a spot of soil to create a pit-and-mound microsite, typically 0.4-m wide x 1-m long with a 30-cm deep pit (Van Damme 1988). Both the two-row and three-row machines used were adjusted to create about 2,300 scarified spots/ha.

The pesticide portion of the study was installed on 2 February 1987 on three sites using three seed treatments and three levels of seed protection in a factorial design. The three seed treatments were control, Ropel™, and Arasan™. Seed protections were none, shade, and screen. All seed used in the study were from general forest cone collections and had a laboratory germination rate of 80 percent. The Ropel treatment was applied by soaking seed in the liquid for 1 min followed by air drying. Latex was mixed with Arasan at a rate of 40 ml/L. This mixture was applied to dry seed until thorough coating took place, then seed were spread on a concrete surface to dry. Shade was provided by a 30 x 30-cm square of aluminum mesh screen with 1-mm square openings. The screen cover used the same aluminum mesh formed into a 30 x 30 x 15-cm box.

On each of the three study sites, a row of nine scarified spots was selected at least 100 m from stand edge. In the center of each spot a sowing area was prepared by turning moist soil to the surface and lightly smoothing it to simulate a freshly-created Bracke spot. For screen spots, a hole about 5-cm deep was made for the box, the box was put into this hole, and soil was placed inside the box. Next, 100 holes were made on each of the 9 prepared spots by pressing 4-mm-diameter hollow tubes attached to a 30x30-cm board in a 10x10 configuration and protruding 1 cm into the bare mineral soil. Then, seed of the selected treatment were placed in these holes and

soil was brushed over the top. After sowing, the shade treatment was installed about 25 cm above the appropriate spots by attaching the piece of screen to four wire pins. Tops of the screen boxes were wired in place to prevent entry by birds or rodents.

The second part of this study was installed on four areas on 3 February 1987. On each site, three adjacent rows of ten scarified spots were selected for use. Next, a row was assigned to receive 2, 5, or 10 seed per scarified spot. Spots were prepared for sowing as explained above. Then seed were placed in a line of holes 1-cm deep and 2-cm apart across the center of the prepared area. After marking the beginning and end of each line with wire pins, seed were covered with soil.

Study sites were checked periodically during the first 4 weeks when evidence of seed predation was recorded. Beginning about 5 weeks after sowing, the number of seedlings on a spot was counted and recorded. These field data were used to calculate seedling percentage, the number of seedlings as a percent of the total number of seed sown, for the pesticide portion of the study. Percent stocking, the number of spots with at least one live seedling, was used to evaluate the second portion of the study. Analyses of variance after arc sine transformation of percents and the Least Significant Difference methods were used to compare treatment means.

Results

In the first part of the study, 7 weeks after sowing neither pesticide significantly increased the seedling percentage over levels on plots sown with untreated control seed (Table 1). Spots with Arasan-treated seed, however, did have more seedlings than those sown with Ropel-treated seed. There were fewer seedlings on spots sown in the open compared with those with shade or complete screen cover. Seven months after sowing, there were no significant differences in seedling percentages due to pesticide treatment of seed. Seedling mortality had been higher on shaded than on screened spots, but both still had significantly more seedlings than the open spots.

Five weeks after sowing, in the second part of the study, spots with five seed had significantly greater stocking than those where only two seed were used (Table 2). Although the use of 10 seed also increased stocking in comparison with 2, it gave no additional increase over the 5-seed-per-spot rate. There was a small decrease in stocking at all rates over the next 5 months. At the end of the study, spots sown with five seed had about three times the level of stocking of those sown with two seed. Although there was considerable variation in stocking between study locations, even on the poorest site stocking was 30 percent for spots sown with five seed. Doubling of the number of seed, from 5 to 10, had no additional effect on percent stocking.

Discussion

Seedling establishment for the first portion of the study was equally good on both shaded and screened spots for all types of seed. Since the

Table 1. The effect of seed treatment and level of protection on seedling percent from direct sown Ocala sand pine seed.

Cover	Seed treatment: Untreated	Arason™	Ropel™	Mean
	seedling percent			
7 weeks after sowing				
Open	65	64	28	52 a[a]
Shaded	71	75	69	72 b
Screened	65	86	76	76 b
Mean	67 ab	75 b	58 a	
7 months after sowing				
Open	56	48	19	41 a
Shaded	67	51	64	60 b
Screened	64	83	78	75 b
Mean	62 a	61 a	54 a	

[a] Means within a row or a column for each time period not followed by the same letter are significantly different at the 0.05 level.

Table 2. Effect of the number of seed sown per spot on stocking.

Number of seed sown per spot on 2/3/87	Percent stocking on 3/10/87	Percent stocking on 8/25/87
2	30a[a]	23a
5	73b	63b
10	68b	60b

[a] Means within a column not followed by the same letter are significantly different at the 0.05 level.

seed on screened plots had complete protection from seed predators, this illustrates that seed predation was not a significant factor in this study. Thus, it is not surprising that neither of the pesticides used gave an increase in seedling establishment.

Lack of significant seed predation could be partially due to weather

nditions during the study. Average precipitation for February and March 6.3 and 12.7 cm, respectively. Precipitation during February following udy establishment was 19.3 cm, and 26.7 cm during March-- both consid- ably above normal levels. Good rainfall promotes rapid germination which turn reduces exposure time of seed to predation. However, seed were ill exposed to predation for at least 4 weeks before germination began, d seed predation did occur, as digging and empty seed coats were noted ound study spots. The level of predation, however, was not high enough significantly affect seedling establishment. This is contrary to re- lts from past studies (Cooper et al., 1959; Burns and McReynolds 1975) ere seed predation was very severe. Both of these studies were on small eas with surrounding cover for seed predators, while in the present study l plots were a considerable distance from surrounding stands. This indi- tes seed predation is not usually a severe enough problem to justify the e of pesticides when regenerating large Ocala sand pine stands.

Shading the seed after sowing, i.e., the shaded and screened spots, in- eased seedling establishment. This is likely due to lower water loss om shaded spots which would increase seed germination. Although it ould be beneficial, at present there is no way to economically provide ade for direct-sown seed.

The minimum acceptable stocking level for Ocala sand pine is 30 per- nt. The second portion of this study shows that the rate of two seeds r Bracke spot is too low to produce acceptable stocking. Increasing the te to five seeds, however, should provide enough seed to give adequate ocking. Any increase beyond this will not increase stocking and would be steful of costly seed ($110/kg). Since not all seed sown by the Bracke arifier-seeder are dropped in a suitable microsite, the question which mains, "How many seeds to put out with the Bracke scarifier to obtain the sired five well-placed seeds per spot?"

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BORON FERTILIZATION AND THE ROOT MORPHOLOGY OF SHORTLEAF PINE SEEDLINGS INOCULATED WITH PISOLITHUS TINCTORIUS [1]

Mary Anne Sword and Harold E. Garrett [2]

Abstract. Benefits associated with ectomycorrhizal infection are well established. However, exploitation of this symbiosis has been hindered, in part, by the inability to obtain consistently high infection rates. Past research in our laboratory has identified a twofold increase in *Pisolithus tinctorius* [(Pers.) Coker and Couch] ectomycorrhizal infection of shortleaf pine (*Pinus echinata* Mill.) seedlings in response to boric acid fertilization. This response was accompanied by a decrease in root indole-3-acetic acid (IAA) content. Other research investigations have associated the physiological function of boron in plants with root growth. An experiment has been conducted to assess the root system morphology of shortleaf pine seedlings inoculated or noninoculated with *P. tinctorius* and fertilized with none or 25 µg/ml boric acid. Results suggest that boric acid fertilization may enhance lateral root branching and elongation of shortleaf pine seedlings inoculated with *P. tinctorius*. This response, attributed to interaction between ectomycorrhizal root IAA and boric acid, may have resulted in increased ectomycorrhizal colonization.

Introduction

In the regeneration environment, survival of conifer seedlings is dependent upon efficient root growth immediately following planting. Both root morphology and elongation rate contribute to efficient root growth and are responsible for interfacing between root and soil. Past research has indicated that physiological processes within the root system may be manipulated by exogenous stimuli such that root morphology and elongation rate are altered (Hess 1969, Torrey 1986). Perhaps, exogenous stimuli could be used to modify the morphology and elongation rate of nursery- and greenhouse-grown conifer seedling root systems resulting in increased interfacing between root and soil. Direct advantages of this response would include increased exposure to indigenous mycorrhizal propagules and subsequent enhancement of mineral nutrient and water absorption. Finally, survival following outplanting, would improve.

The micronutrient, boron, has been identified as necessary for emergence of root primordia (Cohen and Lepper 1977; Jarvis et al., 1984; Ali and Jarvis 1988). Early work of Warington (1923) identified boron as essential for plant growth and

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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dicated that it has a strong effect on root system morphology. Further search has indicated that boron is necessary for root elongation (Whit-ngton 1959, Albert 1965, Cohen and Lepper 1977, Tang and dela Fuente 86).

Synergism between auxin compounds, produced by ectomycorrhizal fungi, d boron may result in both increased root primordia development and in-eased root primordia elongation such that root system morphology is im-oved. Promotion of root growth by boron has been attributed to an inter-tion between auxins and boron (Jarvis et al., 1984; Ali and Jarvis 1988). i and Jarvis (1988) found that an optimum exogenous concentration of ther indole-3-acetic acid (IAA) or indole-3-butyric acid (IBA) and boric id resulted in maximum adventitious lateral root formation in mung bean haseolus aureus Roxb. cv. Berlin) cuttings. Interaction between IAA and ron has also been reported by Mitchell et al. (1986) who found that ecto-corrhizal inoculation of shortleaf pine (Pinus echinata Mill.) seedlings th Pisolithus tinctorius [(Pers.) Coker & Couch] resulted in elevated ot IAA content. However, boric acid fertilization of these ectomycorrhi-l seedlings resulted in a dramatic reduction in IAA level. In addition, ric acid fertilization has resulted in increased ectomycorrhizal coloni-tion of shortleaf pine by P. tinctorius (Mitchell et al., 1987).

The objectives of this experiment were to evaluate root system morphol-y and ectomycorrhizal colonization of 12-week old greenhouse-grown short-af pine seedlings inoculated or not inoculated with P. tinctorius and rtilized with 0 or 25 µg/ml boric acid. Specifically, lateral root hier-chy, short roots and root primordia were quantified. Subsequently, the lationship between root system morphology and ectomycorrhizal coloniza-on by P. tinctorius was assessed.

Materials And Methods

Full-sib shortleaf pine seed (improved source: USDA Forest Service, kansas) was surface sterilized in 0.5 percent NaClO (10 percent Clorox^{tm}) r 15 seconds and cold stratified for 30 days at 4°C (USDA 1974). The owth medium was 1:1:2:2 (v/v/v/v) peat moss-vermiculite-sand-perlite ich was sterilized with methyl bromide. Stratified seed were sown, four ed per cavity, in 0.5 L Tinus Spencer-LeMaire root trainer containers. e-half of the containers were inoculated, 1:7, with vegetative inoculum P. tinctorius isolate 306 (Mycorr Tech Inc., Pittsburgh, PA). oculation was done by thoroughly mixing 0.25 L of vegetative inoculum th 1.75 L of growth medium and pouring the 2.0-L volume into the four vities of individual containers. Following germination, seedlings were inned to one per cavity.

After 90 percent germination, a 16-h photoperiod was implemented using gh-pressure sodium vapor lamps. Throughout this photoperiod, photosyn-etically active radiation was approximately 544 µE m^{-2} sec^{-1}. Seedlings re watered semiweekly throughout the initial 4 weeks of the cultural per-d. Four weeks following 90 percent germination, fertilization began.

Seedlings were fertilized semiweekly with 20 ml of modified Hoagland's nutrient solution (Mitchell 1984). Six weeks following 90 percent germination, boric acid fertilization treatments were initiated. With the exception of 0.006 µg boric acid in 20 ml volumes of the modified Hoagland's nutrient solution, seedlings received none or 0.5 mg of boric acid semiweekly. Following initiation of fertilization, seedlings were watered when the growth medium appeared dry.

This experiment utilized a randomized complete block design with four blocks. Treatments were no inoculation or inoculation with P. tinctorius and fertilization with 0 or 25 µg/ml boric acid applied to the soil. Twelve weeks following 90 percent germination, 16 containers, one per treatment and block, were randomly harvested. Dependent upon analysis, data represent the mean of two or four seedlings per container. As a result, means represent measurements of 32 or 64 seedlings.

Root systems were washed free of growth medium using tap water. Growth parameters measured on four seedlings per container included shoot length, root collar diameter, number of branches, shoot and root dry weights (72 hr, 65°C), and root system length. Shoot length was defined as the distance from root collar to tip of stem. Root collar diameter was defined as the stem diameter at the root collar. Following assessment of ectomycorrhizal colonization and root system morphology, root system length was measured photoelectronically using the line intersect method of Rowse and Phillips (1974).

Two of four seedlings per container were randomly selected for quantification of ectomycorrhizal colonization and root system morphology. The remaining two seedlings were used for analysis of new lateral root growth.

Ectomycorrhizal colonization was determined using the method of Mitchell et al. (1987). The diffusion of ectomycorrhizal colonization throughout the root system was measured as the percentage of primary lateral roots colonized. Colonization was expressed as presence of at least one mycorrhizae on primary lateral roots. The intensity of ectomycorrhizal colonization was quantified as the number of mycorrhizae per infected primary lateral root. Mycorrhizae were characterized by the presence of a fungus mantle or swollen appearance when compared to uninfected short roots.

Following identification of primary lateral roots, secondary and tertiary lateral roots and short roots were quantified using a stereoscope. Criteria used for identification of lateral roots and their position in root system hierarchy were a visual diameter less than that of adjacent short roots, emergence of one or more short roots and branching from an immediately lower order lateral root. Short roots were defined as roots which were less than or equal to 0.5 cm in length and which lacked any emerging roots.

Following identification of lateral root hierarchy and quantification of short roots, 0.25 g of root tissue was randomly subsampled and stained for quantification of root primordia. Using a modification of the procedure of Wilcox (1968), root tissue was cleared in 0.5 percent NaClO (10

ercent Clorox™) for 1 hour, rinsed three times with distilled water, sub-
ersed in distilled water for 1 hour, and then submersed in 0.001 percent
queous safranin. Following 24 hours, meristematic areas of root primordia
ere visible through root cortical tissue and were counted using a stereo-
cope.

New lateral root growth was excised from two seedlings per container.
ew roots were counted and their lengths measured. Criteria used for iden-
ification of new roots were lightness in color when compared with remain-
ng root system and a length greater than or equal to 0.5 cm.

Data were subjected to an analysis of variance. Differences between
reatment means were compared using the LSD test at $P \leq 0.05$ and $P \leq 0.10$.

Results

Shoot and root growth of shortleaf pine seedlings inoculated with P.
inctorius were significantly greater than those of noninoculated seedlings
Table 1). Six weeks following initiation of semiweekly boric acid appli-
ations, shoot growth of 12-week-old seedlings was not significantly af-
ected by boric acid treatment. However, boric acid fertilization treat-
ent resulted in a significant increase in the root system length of
eedlings inoculated with P. tinctorius when compared with those inoculated
ut not receiving boric acid fertilization treatment. No boric acid fer-
ilization treatment effect was observed in either the root dry weights of
noculated or noninoculated seedlings or the root system length of noninoc-
lated seedlings.

Table 1. Growth of 12-week-old shortleaf pine seedlings inoculated or not inoculated with Pisolithus tinctorius and fertilized with 0 (-B) or 25 µg/ml (+B) boric acid.

Variable (units)	Noninoculated		Inoculated	
	-B	+B	-B	+B
Shoot length (cm)	4.3 a*	4.6 a	4.8 a	5.0 a
Root collar dia. (cm)	0.16b	0.15b	0.19a	0.19a
Number of branches	3.6 b	4.0 b	5.5 a	5.6 a
Shoot dry weight (g)	0.18b	0.18b	0.34a	0.38a
Root dry weight (g)	0.09b	0.08b	0.15a	0.15a
Root system length (cm)	249 bBC	247 bC	289 abB	339aA

* Means within a variable followed by the same lower or uppercase letter are not significantly different at $P \leq 0.05$ or $P \leq 0.10$, respectively, using the LSD test.

Quantification of lateral root hierachy indicated that, although r significant differences were found. Boric acid fertilization treatment ap peared to increase lateral root branching of seedlings inoculated with P *tinctorius* (Table 2). The number of primary lateral roots of 12-week-ol shortleaf pine seedlings was unaffected by ectomycorrhizal inoculation an boric acid fertilization treatments. However, the numbers of secondary an tertiary lateral roots on root systems of seedlings inoculated with P *tinctorius* were increased 41 and 74 percent, respectively, due to bori acid fertilization treatment.

Table 2. Quantification of lateral root hierarchy associated with 12-week-old shortleaf pine seedlings inoculated or not inoculated with *Pisolithus tinctorius* and fertilized with 0 (-B) or 25 µg/ml (+B) boric acid.

Variable (units)	Noninoculated		Inoculated	
	-B	+B	-B	+B
Primary lateral roots (#)	20.1*	20.2	19.9	20.1
Secondary lateral roots (#)	16.8	18.2	18.2	25.7
Tertiary lateral roots (#)	0.7	2.5	2.3	4.0

* No significant differences were detected at $P \leq 0.05$ or $P \leq 0.10$ using the LSD test.

New root growth of 12-week old seedlings was significantly affected b both inoculation and boric acid fertilization treatments (Table 3). Th number of actively elongating lateral roots was unaffected by inoculatio and boric acid fertilization treatments. However, the length of this ac tively elongating lateral root tissue was significantly greater in inocu lated seedlings when compared to that of noninoculated seedlings. More over, boric acid fertilization treatment significantly increased ne lateral root length of noninoculated seedlings, relative to entire roo systems. Although not significant, boric acid fertilization treatment als resulted in a 15 percent increase in the percentage of new lateral roo length in inoculated seedlings.

Of shortleaf pine seedlings inoculated with *P. tinctorius*, those fer ilized with boric acid had significantly fewer root primordia when compare with inoculated seedlings not receiving boric acid fertilization treatmen (Table 4). Seedlings inoculated with *P. tinctorius* had a significantl greater quantity of root primordia when compared to those that were not in oculated. In contrast, inoculated and noninoculated seedlings that wer fertilized with boric acid had similar quantities of root primordia.

Inoculation with *P. tinctorius* significantly reduced the number o short roots per length of root system when compared to noninoculated see

ngs (Table 4). Boric acid fertilization treatment had no significant ef-
ct on the quantity of short roots on 12-week-old seedling root systems. However, seedlings inoculated with P. tinctorius and fertilized with boric acid did have 16 percent more short roots when compared to inoculated seedlings not receiving boric acid fertilization. This response can be attributed to the boric acid-induced increase in root system length of seedlings inoculated with P. tinctorius, as previously reported.

Table 3. New lateral root growth of 12-week-old shortleaf pine seedlings inoculated or not inoculated with Pisolithus tinctorius and fertilized with 0 (-B) or 25 µg/ml (+B) boric acid.

Variable (units)	Noninoculated		Inoculated	
	–B	+B	–B	+B
Number of new roots *	14.0 a**	14.6 a	16.1 a	18.9 a
Length of new roots (cm)	12.6 c	18.2 bc	23.5 ab	30.4 a
Percent new root length/ total root length	3.9 b	6.1 a	6.6 a	7.6 a

* New roots were characterized as lateral roots that were white or light in color and ≥ 0.5 cm in length.

** Means within a variable followed by the same letter are not significantly different at P ≤ 0.05 using the LSD test.

Table 4. Primordia, ectomycorrhizae, and short roots associated with root systems of 12-week-old shortleaf pine seedlings inoculated or not inoculated with Pisolithus tinctorius and fertilized with 0 (-B) or 25 µg/ml (+B) boric acid.

Variable (units)	Noninoculated		Inoculated	
	–B	+B	–B	+B
	-------- Root primordia ----------			
Number/cm root length	0.15 b	0.20 b	0.48 a	0.15 b
	Ectomycorrhizae + Short Roots (uncolonized)			
Number/seedling	442 a *	467 a	395 a	460 a
Number/cm root length	1.8 a	2.0 a	1.4 b	1.4 b

* Means within a variable followed by the same letter are not significantly different at P ≤ 0.05 using the LSD test.

Assessment of ectomycorrhizal colonization indicated that boric acid fertilization treatment significantly increased the spread of P. tinctorius colonization (Table 5). The percentage of primary lateral roots colonized by P. tinctorius was 22 percent greater in response to boric acid fertilization. However, the intensity of ectomycorrhizal colonization on seedling root systems was unaffected by boric acid fertilization.

Table 5. Ectomycorrhizal colonization of 12-week-old shortleaf pine seedlings inoculated or not inoculated with Pisolithus tinctorius and fertilized with 0 (-B) or 25 μg/ml (+B) boric acid.

Variable	Noninoculated		Inoculated	
	-B	+B	-B	+B
Percent primary lateral root infection *	6.2 bC**	0.3 bC	77.8 aB	94.8 aA
Infection points/primary lateral root	2.8 b	0.6 b	14.1 a	14.2 a

* Percent primary lateral root infection = (Number of colonized primary lateral roots/total number of primary lateral roots) x 100.

** Means within a variable followed by the same lower- or uppercase letter are not significantly different at $P \leq 0.05$ or $P \leq 0.10$, respectively, using the LSD test.

Discussion

Past research has suggested that boric acid fertilization is beneficial for synthesis of mycorrhizal symbioses. However, the effect of boric acid fertilization on mycorrhizal colonization appears to be dependent upon host and fungus species. Lambert et al. (1980) found that boric acid fertilization of alfalfa (Medicago sativa L.) seedlings inoculated with Glomus fasiculatus [(Thaxt. sensu Gerd.) Gerd. & Trappe] resulted in an 88 percent increase in root infection. However, they also found that boric acid fertilization of alfalfa seedlings inoculated with Glomus mossae [(Nicol. & Gerd.) Gerd. & Trappe], and red clover (Trifolium pratense L.) seedlings inoculated with Gigaspora gigantea [(Nicol. & Gerd.) Gerd. and Trappe] resulted in only 10 and 16 percent increases in root infection, respectively.

In the present experiment, boric acid fertilization had no effect on the number of mycorrhizae per infected primary lateral root of 12-week-old shortleaf pine seedlings inoculated with P. tinctorius. However, fertilization with boric acid did result in a slight enhancement in the spread of colonization by P. tinctorius throughout the root system. The 22-percent increase in primary lateral root infection is similar in some ways to results obtained by Mitchell et al. (1987). Using similar host and fungus

number of mycorrhizae per infected primary lateral root and the percentage of primary lateral roots infected by *P. tinctorius*, respectively, in response to boric acid fertilization following a 16-week cultural period. Similarities in the trend but differences in the intensity of the ectomycorrhizal response to boric acid fertilization treatment suggests that, in addition to host and fungus species, seed and fungal isolate sources as well as cultural environment may dictate the effect of boric acid fertilization on mycorrhizal colonization. Variation in colonization rates between the present experiment and that of Mitchell et al. (1987) illustrates the sensitivity of the shortleaf pine-*P. tinctorius* ectomycorrhizal association to boric acid fertilization and the need for better definition of conditions under which optimum ectomycorrhizal colonization is obtained.

Root morphological changes often accompany enhanced mycorrhizal colonization which occurs in response to boric acid fertilization. Lambert et al. (1980) found that the root system length of 15- and 30-day-old endomycorrhizal alfalfa seedlings increased 100 and 92 percent, respectively, due to boric acid fertilization. Mitchell et al. (1987) found a reduction in the number of primary lateral roots of 16-week-old shortleaf pine seedlings inoculated with *P. tinctorius* due to boric acid fertilization. However, although not significant, Mitchell et al. (1987) also found 38 and 17 percent increases in root dry weights of 16-week-old shortleaf pine seedlings inoculated with *P. tinctorius* and foliar- and soil-fertilized with boric acid, respectively. An increase in root dry weight but a reduction in number of primary lateral roots of shortleaf pine seedlings inoculated with *P. tinctorius* in response to boric acid fertilization suggests that lateral root branching and/or short root production may have been altered.

Following a 12-week cultural period, we found that root dry weights of shortleaf pine seedlings inoculated with *P. tinctorius* were unaffected by boric acid fertilization. However, the root system length was significantly greater than that of seedlings inoculated with *P. tinctorius* but not fertilized with boric acid. Perhaps specific fungus-host interactions in the presence of boric acid resulted in a physiological environment which was conducive to root system development.

Past research has suggested that *P. tinctorius* is capable of producing indole-3-acetic acid (IAA) (Ek et al., 1983; Mitchell et al., 1986). Mitchell et al. (1986) determined the IAA content of uninoculated shortleaf pine seedling root tissue as approximately 120,000 ng/mg dry weight. Ek et al. (1983) found that one isolate of *P. tinctorius*, grown *in vitro* for 5 weeks, produced 19,760 ng/mg dry weight; whereas, a second isolate of *P. tinctorius* only produced 840 ng/mg dry weight when grown *in vitro* for the same period of time. Ectomycorrhizal fungus-produced IAA may supplement endogenous compounds. As a result, inoculation with an isolate of *P. tinctorius*, known to produce large quantities of IAA, may result in elevated root tissue IAA content. This was demonstrated by Mitchell et al. (1986) who found a 2.25-fold increase in the IAA concentration of shortleaf pine seedling root tissue due to inoculation with *P. tinctorius*. Physiological functions, such as those involved in root development, which are regulated by IAA, may be modified by ectomycorrhizal fungus-induced elevated root IAA content.

Boric acid fertilization may further modify the physiological environment in which root development occurs. Furthermore, boron nutrition has been associated with the metabolism of IAA in plants. Boron may regulate transport of IAA from the site of synthesis by altering membrane function (Pollard et al., 1977; Goldbach and Amberger 1986; Schon et al., 1990). As a result, boron deficiency may be associated with elevated IAA concentrations (Smirnov et al., 1977). In addition, past research has indicated that catalytic oxidation of IAA may be modified by boron nutrition (Smirnov et al., 1977; Bohnsack and Albert 1977; Mitchell et al., 1986).

Interaction between fungus-induced elevated IAA and boron may result in alteration of root morphology and subsequently, mycorrhizal colonization. Root developmental processes which may be influenced by interaction between ectomycorrhizal fungus- induced, elevated IAA and boric acid include the rate of root primordia formation, the quantity of root primordia which elongate and root elongation rate (Torrey 1956; Pecket 1957; Whittington 1959; Blakely 1972; Cohen and Lepper 1977; Jarvis et al., 1984; Ali and Jarvis 1988; MacIsaac et al., 1989). In our experiment, the number of primordia in root systems of shortleaf pine seedlings inoculated with P. tinctorius but not fertilized with boric acid compared to those of seedlings in the remaining three treatments, suggests that inoculation with P. tinctorius may have resulted in higher concentrations of root IAA which stimulated induction or initiation phases of root primordia formation.

Following enhanced development of organized root primordia under conditions of elevated IAA, root primordia elongation in shortleaf pine seedlings inoculated with P. tinctorius may have been inhibited. Although elevated root IAA content may be beneficial for development of root primordia, these conditions may be inhibitory toward their elongation (Thimann 1936; Blakely et al., 1972; Jarvis et al., 1984). Other studies have suggested that root primordia elongation may be regulated by both auxin and cytokinin (Blakely et al., 1972; Wightman and Thimann 1980; MacIsaac et al., 1989).

Application of boron to primary roots of seedlings or the hypocotyl of cuttings promotes root primordia elongation (Whittington 1959; Albert and Wilson 1961; Cohen and Leppers 1977; Jarvis et al., 1984; Ali and Jarvis 1988). Cohen and Leppers (1977) determined that boron was necessary for cytokinesis in root merisitems. Other studies have indicated that boron may regulate cytokinesis by modification of ribonucleic acid (RNA) metabolism (Dave and Kannan 1980, Ali and Jarvis 1988).

In our experiment, after 12 semiweekly applications of 20 ml of 25 µg/ml boric acid, lateral root branching of seedlings inoculated with P. tinctorius was enhanced. Perhaps inoculation with P. tinctorius resulted in elevated root IAA content such that the rate of root primordia production increased. Initiation of boric acid fertilization treatments 6 weeks following 90 percent germination may have led to either reduced IAA content or a more favorable IAA:cytokinin ratio such that the number of primordia elongating into lateral or short roots was increased. As a result, root primordia may have been "released" for elongation leading to an increase in secondary and tertiary lateral roots. This sequence of events may explain

oth reduction in the number of root primordia and increase in the number f secondary and tertiary lateral roots of inoculated shortleaf pine seed-ings following boric acid fertilization.

We found that new lateral root growth was stimulated by boric acid ertilization. The percentage of root system which was new lateral root rowth increased 56 percent in noninoculated seedlings, but only 15 percent n seedlings inoculated with P. tinctorius. These results suggest that the ction of boric acid may not have been as strong in inoculated as in non-noculated seedlings. However, lateral root branching analyses do not sup-ort this possibility. More likely, the availability of boric acid for in-eraction with IAA and subsequent modification of root morphology may have ecome increasingly limiting in seedlings inoculated with P. tinctorius. s the cultural period progressed, development of a dense fungal network, oth internal and external to the root system, may have restricted boric cid movement into the root and, as a result, reduced the effect of boron n root development of ectomycorrhizal seedlings when compared to that of oninoculated seedlings.

In our study, boric acid fertilization was initiated early during de-elopment of the ectomycorrhizal association. At this time, boric acid may ave easily diffused through the growth medium and into root tissue. As a esult, lateral and short root formation may have been enhanced by inter-ction between P. tinctorius-produced IAA and boric acid. However, further evelopment of the ectomycorrhizal association, which was accompanied by roliferation of the fungus mantle, extramatrical hyphae and rhizomorph-ike structures, may have presented an increase in potential sites for ixation of boric acid. As a result, less boric acid may have diffused to ocations of primordia development within the host.

In conclusion, our findings indicate that boric acid fertilization of nortleaf pine seedlings inoculated with P. tinctorius resulted in an in-rease in root system length which was attributed to an increase in lateral oot branching and elongation. This response may be valuable for improve-ent of conifer seedling root system morphology and synthesis of ectomycor-nizal associations. However, results of this study also suggest that urther definition of fungus, host and cultural environment characteristics s well as the optimum timetable for boric acid fertilization is necessary or maximization of the root morphological response to boric acid ertilization.

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EARLY GROWTH AND DEVELOPMENT OF SEEDLING-ORIGIN AND SPROUT-ORIGIN STEMS OF YELLOW-POPLAR [1]

Robert T. Deen [2]

Abstract. Even-aged stems of both sprout-origin and seedling-origin yellow-poplar (Liriodendron tulipifera L.) occurring on the same sites and of the same age were compared to evaluate differences in growth and development between the two reproduction types. Sprout-origin stems were larger than seedling-origin stems on all sites and for all ages up to 24 years, in these parameters: diameter at breast height; volume, both inside and outside bark; and crown length. Polymorphic, base-age 25 site curves were developed separately for sprout-origin and seedling-origin stems of yellow-poplar. The base-age 25 curves for seedling- and sprout-origin yellow-poplar were synthesized with the appropriate set of Beck's base-age 50 curves to yield two new sets of base-age 50 site index curves for yellow-poplar. These new curves show that ignoring stem origin, whether sprout or seedling, can result in biased estimates of future yields from young yellow-poplar stands.

Introduction

Yellow-poplar (Liriodendron tulipifera L.) is one of the more important hardwood species in the Eastern United States due to its extensive range and excellent silvical traits, i.e., rapid growth and large size. Yellow-poplar grows best on a variety of sites, from well-drained stream bottoms and sheltered coves to gentle, concave slopes (Braun 1950). The soils usually associated with good to excellent yellow-poplar site are deep, well-drained, and loose-textured (USDA 1965, Beck and Sims 1983). Seldom does yellow-poplar grow well in poorly-drained or very dry situations (McCarthy 1933). Yellow-poplar, then, is a site-sensitive species and it is important to recognize and to assess accurat the site potential for yellow-pop management.

The use of the tree itself the best indicator of a site's tential for growth of that speci Total height at a given age is measure most commonly employed site evaluation. Yellow-poplar well-suited to height measurement it exhibits an excurrent growth f making height measurement straig forward and easy to obtain. Al site index has proven a reliable dicator of site quality for yell poplar (Beck and Della-Bianca 198

According to Zahner and Phill (1981) there is little informat available on the development seedling yellow-poplar vs. spr yellow-poplar on the same si There is also scarce informat generally on development of copp forests in the Southeast. Evide exists showing that sprout-ori stands of hardwood occur commo throughout the eastern hardwood gion (Beck 1977; Zahner et a

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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1982). Studies are needed on existing coppice stands to provide information necessary for proper management of sprout-origin stands in the Southeast.

At present, four sets of site index curves are available for use with yellow-poplar: southern Appalachian curves (Beck 1962), central Appalachian curves (Schlaegel et al., 1969), Piedmont curves (Beck 1962), and region-wide curves (McCarthy 1933). The preceding sets of curves, except McCarthy's, were derived from height-age observations of mostly older stands, some from age 20, but many up to 100 years of age, and do not accurately reflect early growth patterns. McCarthy's curves included data from a few stands as young as 10 years old, but the influence of many older stands may have obscured early growth patterns in harmonized curves.

These existing site index curves for yellow-poplar do not differentiate between the large height growth differences of seedling-origin and sprout-origin stems. With yellow-poplar, establishing early dominance and remaining in the overstory throughout its life, the heights of dominant and co-dominant stems in young stands can be a good and reliable estimate of site quality if differentiation of seedling- and sprout-origins can be made.

Reliable site index curves should be developed to reflect accurately the early patterns of growth for sprout-origin vs. seedling-origin yellow poplar. Existing site index curves for yellow poplar were constructed by developing a series of harmonized curves based on a single set of height-age measurements (Bruce and Schumacher 1950). These curves disregard age-site sampling bias that may occur. For example, an unequal distribution of older stands may occur on poorer sites, negating the assumption that specific height growth curves are directly proportional to a mean curve for all stands (Beck and Trousdell 1973, Spurr and Barnes 1980). However, height growth patterns may vary strongly (polymorphism) for a species such as yellow-poplar that grows on a diversity of sites, under diverse regeneration conditions, and over a wide geographical range (Jones 1969, Beck and Trousdell 1973, Carmean 1975). To account for the polymorphism that occurs in height growth, site index curves can be constructed from stem analyses that are cognizant of the true growth form of the height-age curve. Site index curves constructed from stem analyses of seedling-origin and sprout-origin stems of yellow-poplar, up to age 20, should accurately reflect growth characteristics of these two stem types.

Rapid juvenile height growth is crucial for seedling-origin stems of yellow-poplar as the seedlings must establish dominance early in their life in order to survive and become a permanent member of the stand. Seedlings of yellow-poplar may grow slowly the first 3 years after which height growth is rapid and is maintained throughout juvenile development. On good sites, yellow-poplar seedlings that are free to grow can form pure stands due to their ability to outgrow competitors (Roach and Gingrich 1968). However, McCarthy (1933) and Kellison et al. (1981) both report that yellow-poplar seedlings are unable to compete with sprouts of yellow-poplar and other hardwoods. Seedling-origin stems of yellow-poplar eventually catch-up and exceed the growth rate of sprout-origin stems in later years (True and Tryon 1966).

Yellow-poplar sprouts comprise a significant proportion of regeneration of harvested stands due to their initial growth rates which greatly exceed that of seedlings and of most other hardwood sprouts (Wendel 1975, Beck 1977). Yellow-poplar sprouts derive their rapid growth rate from the inherited root system of the parent stump that readily provides water, nutrients, and stored foods.

This study provides new information on the growth and development of trees of seedling-origin yellow-poplar vs. sprout-origin yellow-poplar in the same regenerated stands occurring on the same sites. Its general objectives were to determine what interaction takes place between the two reproduction types and how important each component is in the development of future stands. Specific objectives were to: (1) compare the height-age growth characteristics and patterns of sprout-origin vs. seedling origin yellow-poplar trees occurring on the same sites; and (2) develop site index curves for sprout-origin and seedling-origin yellow-poplar trees for early estimation of site quality for yellow-poplar.

Methods

Nine even-aged hardwood stands were selected that contained both seedling-origin and sprout-origin stems of yellow-poplar. Ages for these stands ranged from 4 to 24 years. In addition, three stands were chosen that contained only seedling-origin yellow-poplar stems and two stands chosen contained only sprout-origin yellow-poplar stems. These five stands ranged in age from 4 to 25 years. All stands were well-stocked with regrowth following clearcutting. Stands were selected on a diversity of sites to represent growth of naturally occurring yellow-poplar. Of the 14 stands selected, 11 stands were located in the Piedmont of Oconee and Pickens Counties, South Carolina, at elevations of approximately 1,000 ft. The remaining three stands were located in the foothills of the southern Blue Ridge Mountains at elevations from 1,500-2,000 ft in north Georgia and southwest North Carolina. Yellow-poplar had developed in selected stands from natural regeneration, i.e., seed and stump sprouts, following clearcutting.

Sprout origin was determined from the occurrence of live, multiple stems, single stems that showed remains of dead ancillary stems, or single stems that upon ground level examination revealed remains of the parent stump or dead multiple stems. Seedling-origin stems were identified by close inspection of the stump which displayed typical seedling stem development. The main root system below the stem was excavated to reveal normal seedling-origin development of the taproot. In addition, inspection of the basal cross-sectional disc used to age the trees revealed that the first few annual rings were of small radial increments characteristic of seedling-origin yellow-poplar. Sprout-origin stems, by contrast, have wide radial increments the first few years of annual ring development.

Three dominant and/or codominant crown class stems were selected from each of the origin classes present in each of the 14 stands. Trees that showed signs of top damage or breakage were rejected. Sprout-origin trees selected originated at or below groundline to reduce the possibility of sampling decayed stems.

Selected trees on each site were felled with a chainsaw and measurents were taken along the stem. These measurements included groundline ameter, stump height, stump diameter, diameter at breast height, diameter base of crown, height to live crown, crown length, and total height. The asurement of height to live crown, crown length, and total height gave own ratios and clear length of stems. After measurements were completed each stem, cross-sectional discs were removed at 2-ft intervals along e entire length of the stem. Age of each tree was determined in the lab om the disc removed as close to groundline as possible. This proved itical for aging seedling-origin stems as yellow-poplar seedling height owth proved to be very small, in most cases, the first year.

Preliminary height-age curves were plotted for each tree from age unts and the corresponding height for each disc. The three replicates r each origin class in each stand were compared for uniformity, and an erage height-age curve plotted for each origin class in each stand (Fig. . A family of curves for each origin class was then constructed using aphical curve-fitting techniques (Chapman and Meyer 1949; Husch et al., 63) that pooled all stands (Fig. 2). This step established the basic ape of each of the two sets of curves, one for each origin class. Finly, harmonized site index curves for each origin class were constructed 10-ft site classes at base-age 25 using standard techniques of Bruce and humacher (1950) (Fig. 3). The base-age 25 site index curves for sproutigin and seedling-origin yellow-poplar were compared with one another to aluate differences in shape. Each of the two sets of site curves also was ired with existing published base-age 50 site index curves for yellowplar to determine the combined usefulness for predicting site quality.

Volume was determined for the main stem of each individual tree. Two rpendicular measurements taken across the face of each disc were averaged r diameter. This diameter was then employed in Smalian's formula (Husch al., 1963) to calculate the volume of every 2-ft section of the tree th the exception of the top section. The top section was treated as a ne to obtain volume and was added to the volume of the 2-ft sections to tain total tree volume.

Results And Discussion

As expected, annual height increment of sprout-origin stems exceeded at of seedling-origin stems for the first 5 years on all sites (Fig. 4). nual height increment for sprout-origin stems and seedling-origin stems s approximately equal at age 7-8, after which, annual height increment r seedlings exceeded that of sprouts on all sites sampled. The greater itial height growth of the sprouts enables the sprouts to maintain a eater mean total height than seedlings up to age 25. Sprout-origin stems e able, at the younger ages, to bypass these constraints by being already ll-established in the habitat, or site, and are able to forego the tablishment period.

After the fifth year, annual height increment for sprouts on all sites creased steadily to the upper ages sampled in this study, indicating

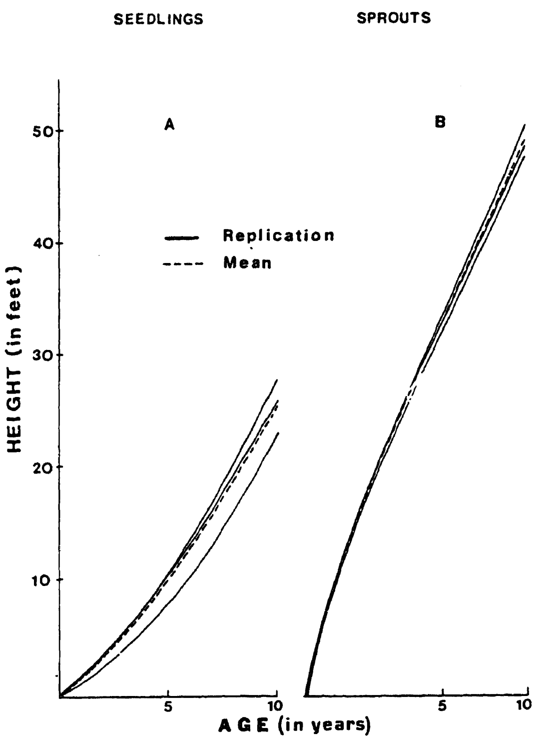


Figure 1. Mean height-age curves for (a) seedling-origin yellow-poplar, and (b) sprout-origin yellow-poplar growing on the same site.

factors other than environmental conditions are involved in the decreasing height increments. The crown and stem, in all likelihood at the older ages grow in size relative to the supporting root system. No longer are water and nutrients, along with carbohydrate reserves in the roots, provided in excess amounts. The early advantage of a large food supply is lost.

Seedling height growth is very slow the first 1-3 years, during which time much energy is devoted to developing a strong root system. This period of establishment is the most critical stage in the life of an individual seedling (Spurr and Barnes 1980). This coincides with the period of greatest height growth of sprouts as compared with seedlings, again reflecting the great advantage afforded the sprouts by originating on the parent root system. After the 3-year establishment period, the seedling's root system begins t

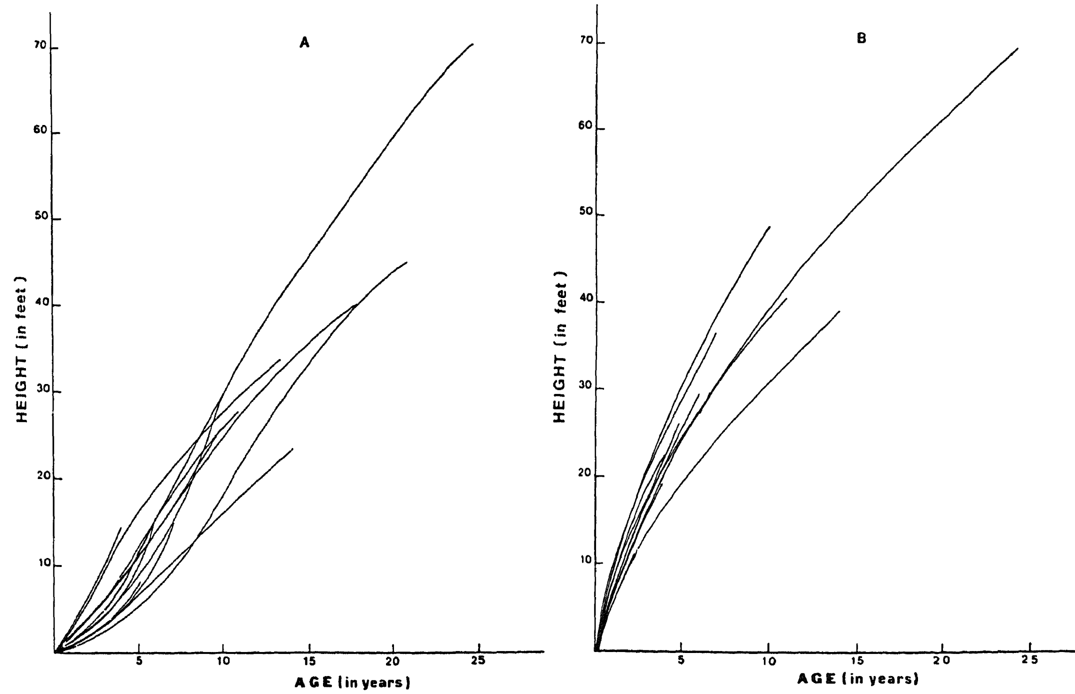


Figure 2. Family of (a) seedling-origin yellow-poplar, and (b) sprout-origin yellow-poplar height-age curves.

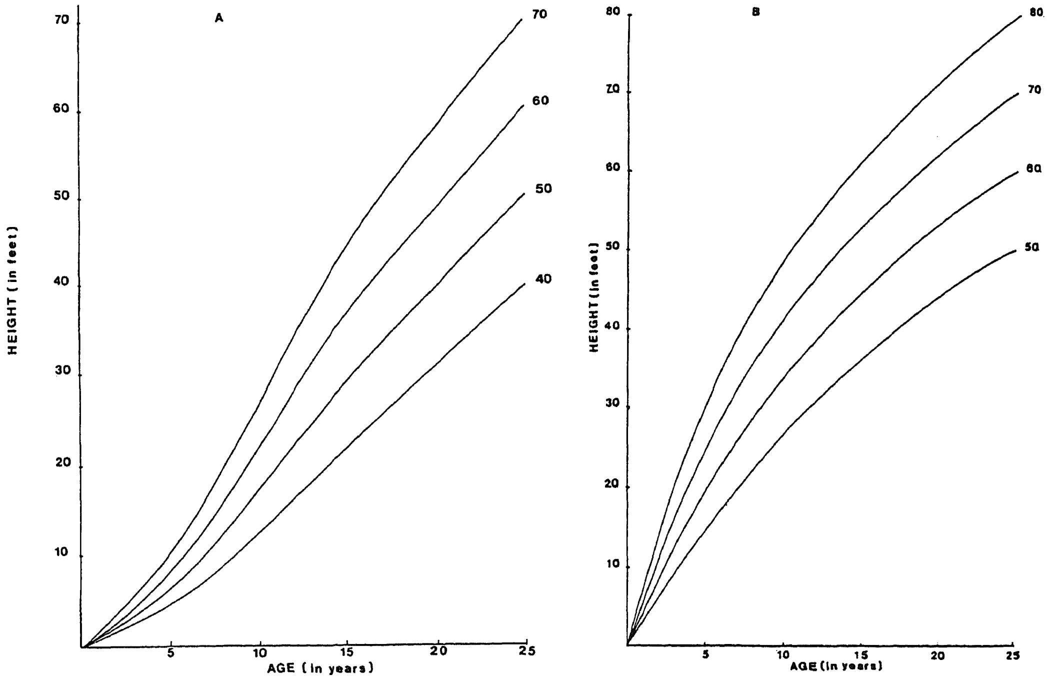


Figure 3. Harmonized site index curves (base-age 25) for (a) seedling-origin yellow-poplar, and (b) sprout-origin yellow-poplar.

provide sufficient amounts of food and water to the crown enabling height growth to proceed at rates characteristic of yellow-poplar.

In comparing sprout-origin stems vs. seedling-origin stems of yellow-poplar, it is important and relevant to view sprout growth as having the advantage of: (1) a large water-nutrient absorbing system, the parent roots, already intact; (2) high levels of stored carbohydrates sufficient to maintain the old root system for several years; and (3) rapidly increasing photosynthetic surfaces as the new sprout unfolds new shoots, all resulting in the bypassing of the critical establishment period. The variable synonymous with a large photosynthetic surface in this study is crown length. Table 1 shows that sprouts have a greater photosynthesizing surface, due to a larger total crown length at all sites and ages, and is reflected in those characteristics serving as sinks for photosynthates, namely dbh, total tree height, and total stemwood volume.

Dbh was approximately twice as large for sprout-origin stems than for seedling-origin stems at all sites and at all ages up to age 24. Total height thereafter is the same for the two origin classes as the rate of height growth is less for sprout-origin stems.

Another characteristic of importance is the amount of clear bole in the lower stem that can be related to sawlog potential. Trees on most sites showed little difference in length of clear boles between sprouts vs. seedlings. Bole length for the seedling-origin stems ranged from 3.3-22.9 ft. For sprout-origin stems, clear bole length ranged from 6.9-24.6 ft. For

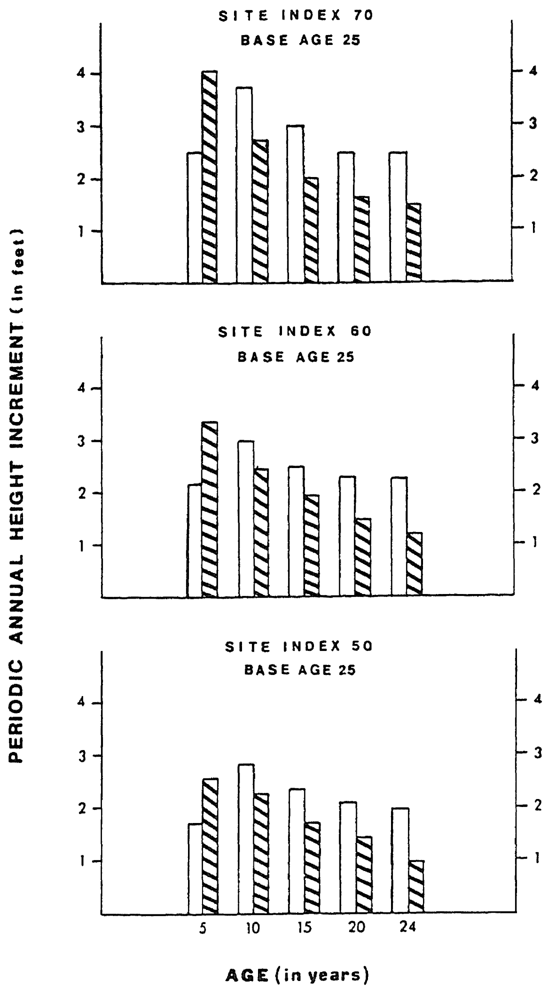


Figure 4. Periodic annual height increment for seedling-origin yellow-poplar (plain bar) vs. sprout-origin yellow-poplar (striped) of the same age growing on land of SI 50, 60, and 70 (base-age 25).

both stem origins, length of clear boles varied from site to site and between ages. This lack of a strong trend can be attributed to site quality differences, degree of competition from site to site, and inherited pruning characteristics. More samples are needed to clarify any relationships for clear boles for sprout and seedling origin stems. However, it is evident that the potential for good sawlog quality does exist for both origin classes and over a range of sites and ages.

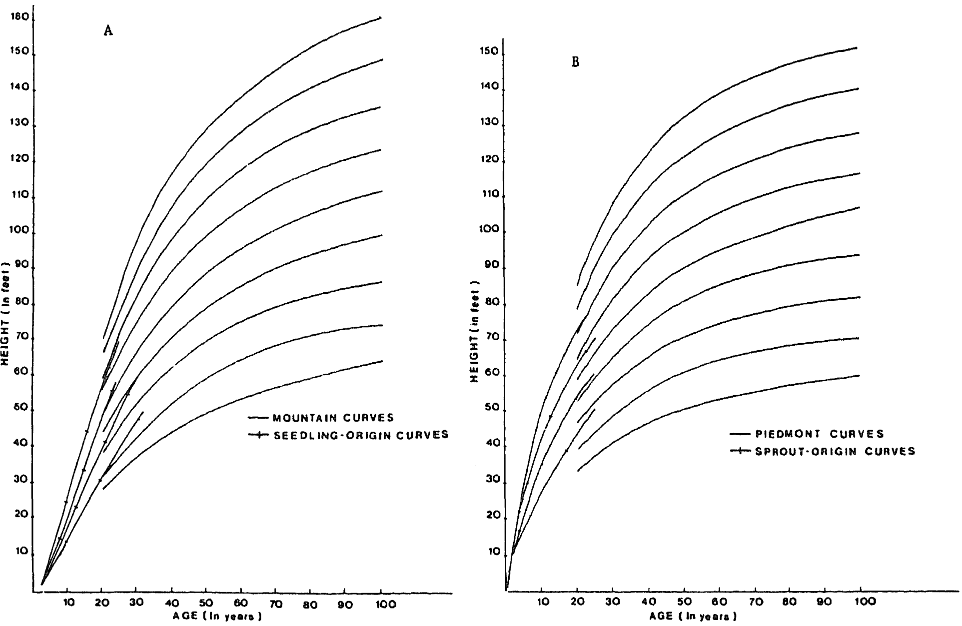
The polymorphic height-age curve shapes that were constructed from stem analysis data provided the basis for determining site index at early ages for seedling-origin and sprout-origin yellow-poplar. The two sets of site index curves were each harmonized separately by graphic methods for a base age of 25 years (Fig. 3). The shapes of these two sets of site index curves were compared with the shape of published site curves for yellow-poplar. Similarities of shape exist between sprout-origin and seedling-origin yellow-poplar site curves from this study and Beck's (1962) Piedmont and Mountain site curves, respectively, for yellow-poplar (Fig. 5). The curves produced from the sprout-origin data of this study fit the shape of Beck's Piedmont curves very well but show little correlation with Beck's Mountain curves (Fig. 6). On the other hand, the seedling-origin site curves derived from this study fit the shape of Beck's Mountain curves very well, but are uncorrelated to Beck's Piedmont curves.

At this point it is appropriate to consider the differences in past and current land-use patterns between the Piedmont and Mountain physiographic regions. The Piedmont has a history of three centuries of habitation by European settlers during which time the land has been under strict land management (Godfrey 1980). Except for bottomlands, it is safe to say that in South Carolina the Piedmont region has been used extensively as farmland, active or abandoned, and as a timber-producing resource, managed or

Origin	Site	Age	Volume exclud. bark [1]	Volume includ. bark	Dbh	Total height	Crown ratio	Height to live crown	Crown length
			----- (ft³) -----		(inch)	(ft)	(percent)	------- (ft) -------	
Seedling			0.04a	0.06a	1.0a	14.6a	45.9a	7.6a	7.0a
Sprout	FGA	4	0.16a	0.20a	1.6b	18.8a	47.4a	9.9a	8.9a
Seedling			0.01a	0.02a	0.4a	8.0a	58.2a	3.3a	4.6a
Sprout	CLT	5	0.47b	0.56b	2.5b	26.2b	74.1b	6.9b	19.3b
Seedling			0.07a	0.08a	1.3a	15.7a	26.7a	11.4a	4.3a
Sprout	PM2	6	0.65b	0.75b	3.0b	29.2b	45.7a	15.8b	13.4b
Seedling			0.06a	0.07a	1.2a	15.2a	40.3a	9.1a	6.1a
Sprout	PM	7	0.99b	1.10b	3.6b	36.5b	51.0a	17.9b	18.6b
Seedling			0.78a	0.94a	3.0a	29.5a	51.3a	14.6a	— [2]
Sprout	OFC	10	3.74b	4.40b	6.3b	44.9b	61.4a	17.4a	— [2]
Seedling			0.30a	0.36a	2.0a	26.0a	37.8a	15.9a	10.1a
Sprout	LC	10	3.70b	4.20b	6.4b	49.3b	66.8b	16.2a	32.9b
Seedling			0.29a	0.35a	2.0a	26.6a	51.1a	13.0a	— [2]
Sprout	TMC	11	2.32b	2.75b	5.1b	41.1b	69.3b	12.6a	— [2]
Seedling			0.18a	0.23a	1.6a	24.0a	41.5a	14.0a	10.0a
Sprout	EMC	14	1.70b	2.12b	4.5b	39.2b	59.9b	15.6a	23.7b
Seedling			2.35a	2.71a	4.7a	45.1a	49.7a	22.9a	22.5a
Sprout	TCA	25	5.14b	6.08b	7.1b	50.0a	50.9a	24.6a	25.4a

[1] Values in the same column followed by the same letter indicate no statistical difference at the 0.05 level.

[2] Missing data.



gure 5. Similarities in height-age curves between (a) seedling-origin llow-poplar with Beck's mountain yellow-poplar height-age curges, and) sprout-origin yellow-poplar with Beck's Piedmont yellow-poplar ight-age curves.

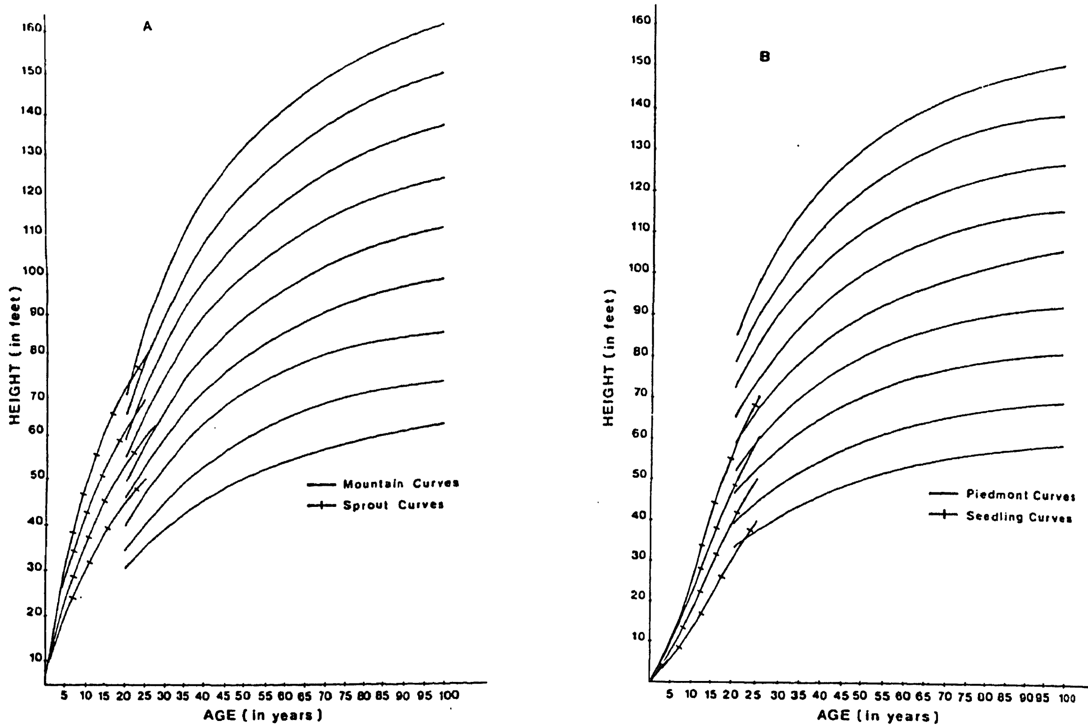


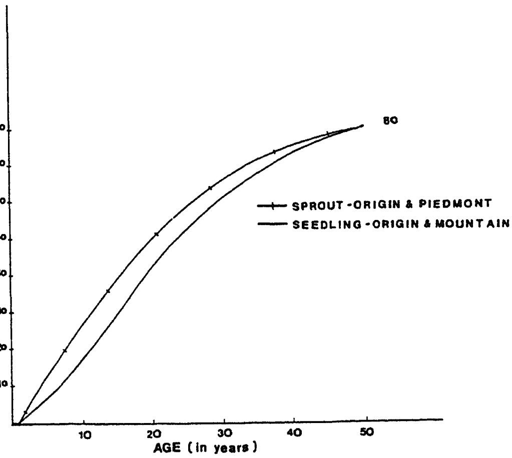
Figure 6. Dissimilarities in height-age curves between (a) sprout-origin yellow-poplar with Beck's mountain yellow-poplar height-age curges, and (b) seedling-origin yellow-poplar with Beck's Piedmont yellow-poplar height-age curves.

otherwise. In either case, the land has been extensively and repeatedly cleared, burned, and cutover; and it follows that a great potential for hardwood sprout regeneration has and does exist in the Piedmont.

The Mountain region has not been subjected to the frequency of timber harvest as has the Piedmont, due mainly to steepness of slopes that limits access (Barrett 1980) and, therefore, minimizes the scope of human activities. This lack of frequent logging allows hardwoods, especially the oaks and yellow-poplar, to reach seed-bearing age and results in stump sizes too large for effective sprouting. The net effect is regeneration mainly from seed.

Beck (1962) states that slope coefficients of his calculated curves for predicting site index for yellow-poplar in the Piedmont and mountains were significantly different, indicating differences in height-age relationships between the two physiographic regions. It is suggested that differences in curve shapes were probably due to prevalence of sprout regeneration of yellow-poplar in Piedmont stands and seedling regeneration in mountain stands.

Beck's (1962) Piedmont and mountain curves converge at age 50 with considerable differences in height growth patterns both before and after this age (Fig. 7). Beck's Piedmont curves couple nicely with the sprout-origin



igure 7. Comparison of sprout- nd seedling-origin curves coupled ith Beck's Piedmont vs. mountain ellow-poplar height-age curves howing dissimilar height-age rowth patterns of yellow-poplar to each SI 80 at age 50.

yellow-poplar height curves observed in this study, reflecting the early height growth advantage sprouts have over seedling-origin stems. After age 50, Beck's mountain curves maintain a superior height growth rate compared with his Piedmont curves, which is characteristic of seedling-origin stems as opposed to sprout-origin stems of the same species. The yellow-poplar site curves developed in this study, after the first 5 years, indicate a faster growth rate for seedling-origin stems than for sprout-origin stems. After 25 years the sprouts still have a somewhat greater total height over seedlings but have a slower growth rate beginning about age 7 or 8. The seedling-origin stems, owing to their greater annual height increment after this age, eventually catch up to and exceed the sprout-origin stems in total height. Thus, ssuming Beck's (1962) Piedmont and mountain curves are, indeed, derived rgely from sprout-origin and seedling-origin stands of yellow-poplar, espectively, sprout-origin yellow-poplar maintains a total height advant- ge over seedling-origin yellow-poplar to age 50, after which seedling- igin yellow-poplar exceeds sprout-origin yellow-poplar in height growth.

An interesting and crucial point derived from the separate curve con- ruction of the two different origin classes, sprouts and seedlings, is at considerable error can result in estimating site index when origin ass is ignored (Fig. 8). The site curves show that seedling-origin and rout-origin stems have different height growth patterns to reach the same te index at 25 years. For instance, at 16 years of age two similar yel- w-poplar stands can yield quite different estimates of site index, if one mainly of sprout-origin and the other of mainly seedling-origin. A edling-origin stand 46 ft in height at 16 years indicates a site index of) ft using the base-age 25 curves for seedling-origin stands. By contrast, sprout-origin stand 46 ft in height at 16 years is actually site index 60 ing the base-age 25 curves for sprout-origin stems. Using the improper t of site index curves for either stand could overestimate or underesti- te site index by as much as a 10-ft site class at age 25. This error is r more serious when using base-age 50 curves. Thus, substantial problems long-range management plans can result from incorrect assumptions of oductivity from site curves that disregard origin of yellow poplar stems.

It is relevant to point out that although total height between the two igin classes becomes nearly equal by age 25 in this study, sprout-origin emwood volume greatly exceeds that of seedling-origin throughout the 25-

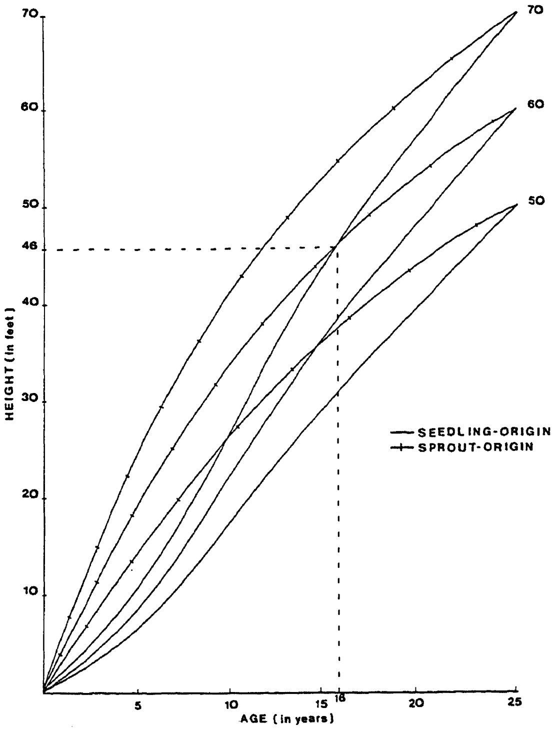


Figure 8. Comparison of sprout-origin and seedling-origin yellow-poplar height-age curves showing discrepancy in site class estimation that will occur if tree origin is ignored.

year period. Sprout stems at least can be utilized for high fiber production over short rotations, and in addition can also grow to sawlog diameter in a shorter period than seedling-origin stems. Seedlings, on the other hand, are free of butt rot often associated with sprout-origin stems. Also, seedling height growth eventually exceeds sprout height growth and stemwood volume may follow the same trends as trees mature. Classically, seedling-origin stems are desired as sawlog products over sprout-origin stems; whereas both sources of regeneration for yellow poplar, seedling and sprouts, are capable of providing quality products.

Acknowledgments

This study took place while the author was a graduate research assistant at Clemson University and was supported by the Southeastern Forest Experiment Station, Asheville, North Carolina, through the Piedmont Hardwoods Silviculture Work Unit at Clemson.

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REGENERATION OF TREE SPECIES 7 YEARS AFTER CLEARCUTTING IN A RIVER BOTTOM IN CENTRAL ALABAMA [1]

Michael S. Golden and Edward F. Loewenstein [2]

Abstract. A mixed bottomland forest stand near the Alabama River was commercially clearcut, with partial injection treatment of noncommercial woody species. Based on inventory data taken 7 years following the harvest, a stand with good potential commercial value is developing. Water plus willow oaks, sweetgum, sugarberry, and green ash were the most abundant species among stems taller than 10 feet. Compared with the preharvest overstory, water plus willow oaks, green ash, and sugarberry have increased their proportions, sweetgum has remained constant, but cherrybark and swamp chestnut oaks have declined. Flooding, herbivory, and low levels of advance regeneration may have contributed to the low numbers of cherrybark oak.

Introduction

Clearcutting as a natural regeneration method for southern bottomland forests has been widely recommended as effective for reestablishing and even increasing the most valuable hardwood species (Kellison et al. 1981, Tolliver and Jackson 1989). However, the results are not always satisfactory (Gresham 1985). Also, because of the wide diversity of site conditions, species mixes, and landowner objectives, the application of a technique as drastic and controversial as clearcutting in these forests calls for as much knowledge and experience as possible. We report here the interim results of a study of a clearcutting application in west-central Alabama.

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Associate Professor and Graduate Research Assistant, Sch. Forestry, Auburn Univ., AL.

Methods

Study Area

The study site is located in the floodplain of the Alabama River near Selma, Dallas County, Alabama. Three soil series are found within the 40-ac site studied: Minter loam-- a fine, mixed thermic Typic Ochraqualf; Congaree loam-- a fine-loamy, mixed, nonacid, thermic Typic Udifluvent; and Canton Bend fine sandy loam-- a fine, mixed, thermic Ultic Hapludalf. The Minter loam areas are poorly drained and are found in lower areas which typically have the water table at or near the surface during the winter and much of the spring. The Congaree and Canton Bend areas are slightly higher and are better drained, although the Congaree soils have the water table near the surface (3-4 ft) during typical winters (Reeves 1979). In normal years, the study site floods for brief periods during December-May.

The stand is owned and managed by Buchanan Hardwoods, Inc., of Selma, AL. Twenty years prior to study installation and treatment, about

1.6 mbf/ac of overmature or poor-quality sawtimber trees were harvested. No cutting occurred between then and the beginning of this study.

Study Design

A square 40-ac area was commercially clearcut in summer of 1982, with utilization of pulpwood (minimum one bolt with 4-inch diameter top) and sawtimber (minimum stump of about 12 inches diameter) trees. Prior to the commercial harvest, the 40-ac area was divided into 16 square 2.5-ac treatment areas. The southernmost 12 of these areas were randomly assigned one of three treatments: inject before (IB), inject after (IA), or check (CC). The IB treatment consisted of injecting all "undesirable" species and pulpwood or smaller-sized hickories (Carya spp.) and elms (Ulmus spp.) several months before the commercial logging operation. Undesirable species were: eastern hophornbeam (Ostrya virginiana), American hornbeam (Carpinus caroliniana), privet (Ligustrum spp.), pawpaw (Asimina triloba), haws (Crataegus spp.), snowbell (Styrax grandifolia), and red mulberry (Morus rubra). The IA treatment consisted of injecting the same species shortly after the logging was completed. No trees 10.5 inches and larger dbh were injected in either treatment. There were four replications of each treatment and the check. The check involved no treatment other than the commercial logging operation. The northernmost four areas (total of 10 ac) received a "cut before" (CB) treatment, where understory trees were felled and pulpwood removed. Notes from the researchers who installed the study leave unclear the degree of understory removal beyond good pulpwood utilization. Cull sawtimber-sized trees of commercial species apparently were not cut in any of the treatments.

Measurements

Prior to any of the treatments, the overstory of each 2.5-ac treatment area was inventoried with a single 0.5-ac circular plot (83.26 ft radius) centered in the treatment area, where all stems larger than 5.5 inches were recorded by species and dbh. The subcanopy trees were inventoried by four 0.01-ac circular plots (11.78 ft radius). A subcanopy plot was centered at 33 ft from the overstory plot center in each of the four cardinal directions. In each of these 0.01-ac plots, all tree stems 5.5 inches dbh and smaller, but taller than 1 ft, were recorded by size and species. Non-tree species such as pawpaw, snowbell, privet, and haws were not included in the data reported here.

The study area was inventoried again in the fall of 1989. At this time, there had been seven full growing seasons since the stand was harvested. It proved impossible to exactly relocate most of the original 0.01-ac subcanopy plots, so the entire 40-ac area was sampled using a system of strip transects. From a randomly located starting point, parallel, 12-ft-wide strips were inventoried, spaced at 330 ft intervals. This provided one strip through each of the four rows of 2.5-ac treatment areas. These strips were divided into 12-ft-long segments for data recording. All tree species were recorded in four size classes: < 1 ft tall; 1-3 ft tall; 3-10 ft tall; and > 10 ft tall. Multiple-stemmed sprouts were treated as one "stem" in the analysis. We report here only on the stems which were > 1 ft tall.

Analysis

Data were grouped into four classes. These were: preharvest overstory, preharvest understory, total 7-year stems taller than 1 ft, and "canopy" 7-year stems (those taller than 10 ft). Stems per acre could be obtained for all classes at both times, so this measure was used for comparisons.

Our inability to relocate the 0.01-ac plots after 7 years, the lack of random installation for the four replications of one of the treatments, and very large variation in species composition within replications of treatment areas before the harvest (standard deviations for stems/ac were typically several times the species means) forced us to conclude that the power and validity of statistical tests among species or species groups between the two measurement times would be suspect at best. Further, there is no basis to expect that the two injection treatments would differ significantly in their impacts on stand composition, so separating them is unjustified. The only treatment comparison with clear potential for impact on stand composition was the injection of noncommercial stems (IB and IA) versus no injection (CB and CC). However, close examination of averages and proportions of total stems by species and species groups (e.g., all commercial species, all oaks, all noncommercial species) indicated that general patterns and relationships (and, in most cases, specific values) were very similar. Apparently, microsite, harvesting, and preexisting variation masked any potential differences among these treatments.

Consequently, we have combined all data from the entire 40-ac site and treated the stand as a case study. As such, it represents results and trends for a specific application of commercial clearcutting, with pulpwood utilization and partial injection treatment of noncommercial woody species.

Results

Preharvest Composition

The preharvest overstory (stems larger than 5.5 inches dbh) averaged 96 trees/ac, totalling 104.5 ft^2/ac basal area. It was dominated by the oaks, which comprised 44 percent of the basal area though just 24 percent of the numbers of stems (Table 1). A number of stems, particularly those of cherrybark oak (Quercus pagoda), exceeded 26 inches in diameter. The other major oaks were swamp chestnut oak (Q. michauxii), water oak (Q. nigra), willow oak (Q. phellos), and a few scattered white oaks (Q. alba). Sweetgum (Liquidambar styraciflua) and sugarberry (Celtis laevigata) were other prominent canopy dominants (Table 1). Other species included green ash (Fraxinus pennsylvanica), red maple (Acer rubrum), American elm (Ulmus americana), and at least two species of hickories (Carya spp.). Commercially valuable species averaged 80 stems/ac (83 percent).

An average of 860 understory trees/ac (5.5 inches or less dbh, but taller than 1 ft) were tallied in the preharvest inventory. Most of the important overstory species were represented in larger numbers, although in smaller proportions, than in the canopy (Table 1). Ash was an exception, occurring in a larger proportion in the understory (12 vs 5 percent). The oaks averaged 135/ac (16 percent), with a small number of overcup oaks (Q. lyrata) included. Water plus willow oaks (combined in the data summaries)

were most prominent (83/ac), but cherrybark oak was scarce (11/ ac) and white oak was absent. As a group, commercially valuable species averaged 506 stems/ac in the understory (59 percent). Understory proportions of the overstory species were skewed by the large number of noncommercial species stems (354/ac; 41 percent). These noncommercial species were mostly shade tolerant species, such as American hornbeam (198/ac) and red mulberry (158/ac).

Table 1. Composition of preharvest stand overstory and understory. Basal area and stem density, and percentages of totals, by species.

Species	Overstory				Understory	
	Basal area		Stem density		Stem density	
	ft²	percent	#/ac	percent	#/ac	percent
Cherrybark oak	18.2	17	5	5	11	1
Swamp chestnut oak	10.6	10	10	11	33	4
Water/willow oak	14.3	14	6	6	83	10
White oak	2.8	3	2	2	0	0
Sweetgum	19.5	19	17	17	19	2
Green ash	5.1	5	5	5	102	12
Sugarberry	14.4	14	16	17	42	5
Other commercial[1]	14.7	14	20	20	217	25
Noncommercial[2]	4.9	5	17	17	354	41
Totals	104.5		96		860	

[1] Includes red maple, elms, hickories, white, and overcup oak.

[2] Primarily American hornbeam, but also flowering dogwood and red mulberry.

Seven-year-old Regeneration

After seven growing seasons, most of the area was dense with a regrowth of seedlings, sprouts, vines, briars, and a few scattered residual trees. A couple of loading areas used in logging were still somewhat open, and a small road traversed the 40-ac area. Patches of chinaberry (*Melia azedarach*) occurred in some sections, but were generally falling behind other trees in growth. Stems of this species were ignored in analyses.

Most of the dominants were 16-25 ft tall at age 7, and a sample averaged 19 ft tall. Thus, it seems reasonable to assume that very few of the stems less than 10 ft tall are likely to become part of the dominant canopy without some manipulation of stand density. Consequently, the stems taller than 10 ft can be considered the best current indication of the canopy composition 10 to 20 years in the future.

A total of 2,283 stems/ac of tree species (excluding chinaberry) was present at age 7 (Table 2), with 1,820 of these (80 percent) being of commercial species. An average of 822 stems/ac were trees taller than 10 ft, with 644/ac (79 percent) being of commercial species. The most abundant species was sugarberry, with 723 stems/ac, or 32 percent. Of sugarberry stems, 119 were more than 10 ft tall (14 percent of this size class). Sweetgum (261/ac; 11 percent) and green ash (162/ac; 7 percent) had respectable numbers among total stems and higher proportions among the canopy size class (137/ac, or 17 percent, and 87/ac or 11 percent, respectively). Scattered loblolly pines (Pinus taeda) seeded in on some of the better-drained areas, averaging 19 total stems/ac (0.8 percent) and 5 stems/ac taller than 10 ft (0.6 percent). Most of the 14 pine stems/ac shorter than 10 ft were in free-to-grow positions in openings (from loading areas or by the road) so they can be expected to remain part of the future stand.

Table 2. Tree species composition of the developing stand 7 years following clearcutting. Density and percentages of total stems, by species for all stems taller than 1 ft and for stems taller than 10 ft.

Species	All stems		Stems >10 ft tall	
	#/ac	percent	#/ac	percent
Cherrybark oak	11	<1	1	<1
Swamp chestnut oak	20	1	12	1
Water/willow oak	289	13	142	17
Sweetgum	261	11	137	17
Green ash	162	7	87	11
Sugarberry	723	32	119	14
Loblolly pine	19	1	5	1
Other commercial[1]	334	14	142	17
Noncommercial [2]	462	20	178	22
Totals	2283		822	

[1] Includes red maple, elms, hickories, and overcup oak.

[2] Primarily American hornbeam and red mulberry.

The total number of oaks was 324/ac (14 percent), and they comprised about 19 percent (157/ac) of the canopy size class. Water plus willow oaks had the highest population, both among total stems (289/ac; 13 percent) and the canopy class (142/ac; 17 percent). The two highest quality oak species, swamp chestnut oak and cherrybark oak, had very small numbers among the regenerating stand. Swamp chestnut oak had 20 total stems/ac (0.9 percent) and 12/ac taller than 10 ft (1.4 percent). Cherrybark oak averaged just 11 total stems/ac (0.5 percent), and only 0.7 stems/ac taller than 10 ft (0.1 percent).

Discussion And Conclusions

The effect of the injection of noncommercial species, which was conducted on half of the 40 acres, is not clear. Injection should have reduced the stem numbers of most of the species treated, but this could not be established from these data. The more important question, whether or not the injection of undesirable species resulted in an increase in commercially valuable species numbers, could not be determined.

If the composition of stems taller than 10 ft at age 7 is taken as an estimate of the future stand makeup, clearcutting the former stand has produced adequate numbers of potentially valuable trees. The 644 canopy stems /ac of commercial species should be adequate for production of quality sawtimber, although uneven distribution has left scattered areas understocked.

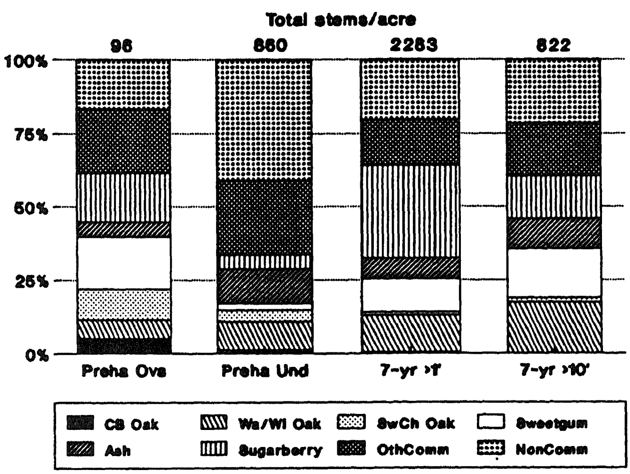

Figure 1. Species composition in percent of total stems for preharvest overstory and understory, and for all stems taller than 1 ft and for canopy-sized (taller than 10 ft) stems at age 7.

Trends in composition can be more easily seen when the proportions of each species for each time and size category are directly compared, as in Figure 1. Probably the most useful comparison is between the species proportions for the pre- and postharvest overstories (the first and last bars of Fig. 1). A general similarity is readily apparent. The slightly higher proportion of noncommercial stems is to be expected in the regenerated stand at this age. The two species which comprise nearly all of the noncommercial stems (American hornbeam and red mulberry) should fade back into the understory as the stand develops further. Assuming then that commercial species will increase in proportion in the coming years at the expense of the noncommercial, species groups in the canopy should achieve very similar proportions to those of the preharvest stand. However, green ash and water plus willow oaks have already increased in comparison to their preharvest canopy proportions (Fig. 1; 11 vs 5 percent and 17 vs 6 percent, respectively).

The largest reductions occurred for two of the "select" oaks (Putnam et al., 1960), swamp chestnut and cherrybark oak (10.6 to 1.4 percent and 5.2 to 0.1 percent, respectively). However, it is possible that present population levels of these species do not represent reductions in numbers of these species in the future stand. For example, their total stem numbers at age 7 were actually higher than in the preharvest canopy (20 vs 10 stems/ac and 11 vs 5 stems/ac for swamp chestnut and cherrybark oak, respectively). Cherrybark oak is able in even-aged stands to overtake (at ages 20-30 years) many other bottomland species which are taller at younger ages (Clatterbuck and Hodges 1988). It is possible that all stems of these two oaks at age 7 may survive and produce dominant overstory stems. However, detailed examination of height distributions weakens this possibility for cherrybark oak. Of its 11 total stems/ac, 4.4 are less than 3 ft tall and could not reasonably be expected to achieve dominance without being released. It is also unlikely that all of the 3- to 10-ft-tall stems will become dominant since some of them are overtopped. So, it seems reasonable to predict that there will ultimately be fewer cherrybark oaks in the future canopy than were present at harvest. Swamp chestnut oak will probably have as many or more stems in the future canopy since it had 12 /ac in the 7-year 10 ft plus canopy, and an additional 5 stems/ac between 3 and 10 ft tall.

It is interesting to note that the total number of cherrybark oak stems at age 7 is almost exactly the same as was recorded for the preharvest understory (11/ac). So in this case, the "advance regeneration" of this species was an accurate predictor of its total numbers in the 7-year stand. This did not hold as well for the other oaks, since water/willow oaks increased more than threefold (389 vs 83 stems/ac) and swamp chestnut oak numbers declined (20 vs 33 stems/ac).

In light of the success of some of the other oaks, the reason for the poorer regeneration success of cherrybark oak is not clear. Its smaller preharvest population made it more sensitive to negative factors and events, such as herbivory and flooding. There appears to be a high population of white-tailed deer (Odocoileus virginianus) in the area. We do not have adequate information to establish the detailed flooding history during the 7 years following cutting, but we speculate that this had an effect on the survival of smaller cherrybark oaks. This species is sensitive to inundation (where the growing tip is covered), particularly during the growing season (Hosner 1960; Jones et al., 1989). The site was flooded briefly during the early summer of 1989. This event is unlikely to have affected the stem count of that same year. However, if such events occurred during the first 2 or 3 years after harvest, it may have killed many small seedlings (particularly those recently germinated), reducing an already small number of cherrybark oaks. This would increase the reliance on taller stems, which would have been primarily sprouts and advance regeneration. We infer from this that a larger amount of advance regeneration (the preharvest understory) would have been required in order to have increased the numbers of cherrybark oak in the new stand. This emphasizes the need to develop large numbers of advance regeneration when managing to increase cherrybark oak in flood-prone areas.

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OAK REGENERATION IN ABANDONED FIELDS: PRESUMED ROLE OF THE BLUE JAY [1]

Robert T. Deen and John D. Hodges [2]

Abstract. Abandoned hayfields on the Noxubee National Wildlife Refuge in central Mississippi contained a high stocking (876-1101 ha) of red oak (Quercus spp.) seedlings. The source of the acorns was not apparent. The fields were located on a terrace not subject to flooding. Also, acorn fall from oak seed trees was not a factor. Therefore, an outside agent--presumably the blue jay (Cyanocitta cristata L.)--was responsible for acorn caching within the fields. Age of red oak stems coincided with termination of management practices, i.e., mowing and burning. The management practices created conditions conducive to acorn caching. Oak rootstocks ranged in age from 5-10 years, indicating that acorn caching occurred over a period of time. Mowing practices resulted in a high percentage of oak coppice stems (93-99 percent) which are better able to compete. The fields will eventually revert to red oak dominated forests.

Introduction

The role of the blue jay (Cyanocitta cristata L.) and rodents in foraging and dispersing acorns has been documented (Chettleburg 1952, Smith and Follmer 1972, Bossema 1979, Darley-Hill and Johnson 1981, Jensen and Nielson 1986, Johnson and Adkisson 1986).

Visual observation indicated that red oaks (Quercus spp.) were regenerating in open fields along Keaton Tower Road on the Noxubee National Wildlife Refuge (NNWR), Noxubee County in central Mississippi. Due to the topographical position of the fields, on terraces overlooking the Cypress Creek floodplain, water transport was dismissed as a mechanism of acorn dispersal. Distance of regeneration from the forest edge coupled with the relatively large-size of red oak acorns negates the role of gravity and wind for acorn dispersal. The purpose of this study was to investigate regeneration of oaks in abandoned fields and the possible role of blue jays in that regeneration.

Literature Review

William Bartram wrote, "The jay is one of the most useful agents in the economy of nature, for disseminating forest trees--these birds are capable, in a few years time, to replant all cleared land (in Johnson and Adkisson 1986)." While the role the jay fulfills in forest regeneration has been recognized for some time, the jay has only recently been recognized within a wider range of the scientific community as an important component of forest ecology. Specifically, jays function in the

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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ocal establishment of oak forests on open sites through acorn caching Chettleburg 1952, Darley-Hill and Johnson 1981) and, on a biogeographical asis, in aiding the rapid northward expansion of oak species from southern efugia following the last glacial episode (Johnson and Adkisson 1986, Page nd Morton 1989).

Aust et al. (1985) reported on the existence of pure oak stands on loodplains and terraces within minor streambottoms of east central Mis- issippi. The major causal factor in the existence of these pure oak tands (at least 70 percent oak) was some form of disturbance, either mow- ng, grazing, or burning. This, they argued, led to the development of prout-origin oak stems better able to compete with other woody vegetation. majority of the stands of their study were on old field or old pasture ites. They noted that flooding and residual oak seed trees could account or the seed source in most of these stands. However, there remained some uestion as to the manner in which acorns were distributed within the tands.

European jay (*Garrulus glandarius* Hart.) adults consume acorns and also egurgitate the acorn meat to their young (Bossema 1979). Hall (1977) re- orts that acorns are a major source of food for blue jays in Florida. corn consumption is directly related to total mast production but, by aching acorns, blue jays insure themselves of a food source later in the ear. Jays relocate their caches and consume the acorn fruit during the all, winter, and early spring. During the late spring-early summer, jays isually identify emergent oak seedlings by their cotyledons and consume he cotyledons or feed them to their young (Harper 1977, Bossema 1979). uring the caching process jays remove one to five acorns from the tree, lace them in their esophagus and bill, and fly to a caching or burial ite. The jay then uses its bill to create an opening in the ground within hich to place an acorn. Acorns are regurgitated and placed singly within hole. The cached acorn is then covered with debris. This process is epeated until all acorns are buried. The placement of acorns in the round and covering them with debris serves to protect the acorns from esiccation and predation, enhancing the probability of germination.

Caching acorns is similar to direct seeding oaks. Direct seeding corns at depths of 2.5-15.0 cm is successful, however, higher germination ercentages occurred at planting depths of 2.5-5.0 cm for nuttall oak (*Q. uttallii* P.) and 5.0 cm for cherrybark oak (*Q. pagoda* Raf.) (Johnson 1981, ohnson and Krinard 1985).

Placing acorns just beneath the surface will not insure complete pro- ection from rodent predation, but if many acorns are cached by jays at a articular site enough may escape predation. Chettleburg (1952) observed hat a single jay could cache 1800 acorns in a 10-day period and, following 5 birds, he determined 200 thousand acorns could be cached during one utumnal period.

Another factor beneficial to germination success of cached acorns is he fact that jays shake collected acorns discarding those that rattle, in- uring that sound acorns are planted (Darley-Hill and Johnson 1981). The

number of acorns that produce seedlings is, in all likelihood, a function of the abundance of acorns produced. Given the propensity of jays to collect and cache acorns (Chettleburg 1952), it follows that in a year of high acorn production more acorns would be buried than could be utilized, resulting in a high number of seedlings. Conversely, in a year of low acorn production there would be a more complete utilization of cached acorns due to a smaller quantity cached and, therefore, a reduced number of seedlings. Bossema (1979) states that given the large number of acorns cached by an individual jay, up to 46 thousand, the probability of complete retrieval of all acorns is unlikely due to the memory required to locate all caching sites, and the probability of death or emigration of the caching jay. These circumstances would lead to germination of the cached acorns.

Blue and European jays transport acorns from collection to caching sites over distances from 1-5 km (0.6-3.0 mi) (Harper 1977, Bossema 1979, Darley-Hill and Johnson 1981). In central Mississippi blue jays have been observed transporting acorns 0.8-1.2 km (0.5-0.75 mi). The northward expansion of the oak species following the last glacial retreat may have been assisted by jays (Johnson and Adkisson 1986, Page and Morton 1989).

Darley-Hill and Johnson (1981) stated that blue jays preferred acorns of willow oak (Q. phellos L.), pin oak (Q. palustris L.), and black oak (Q. velutina Lam.), that range in size from 1.1-1.7 cm in diameter. Jays ignored larger acorns of northern red oak (Q. borealis Michx. F.) and white oak (Q. alba L.). They also found that the blue jay preferred acorns in the weight range of 0.7-3.0 g. Bossema (1979) found that the European jay preferred acorns in the weight range from 2.0-4.0 g. Caching sites preferred by jays appear to be an early successional stage where vegetation is low which permits easy access (Bossema 1979).

Rodents may also place acorns within open fields. Jensen and Nielsen (1986) reported that the invasion of oak into Danish heathlands was due to the wood mouse (Apodemus sylvaticus Kaup), and the bank vole (Clethrionomys glareolus T.). They concluded that the dispersal techniques of the rodents could explain the 300 m advance of oak into the heathland in 100 years. They found that these rodents tended to move acorns an average distance of 24 m from the source tree. By burying acorns away from the source tree the probability of seedling germination and establishment is enhanced by removal of intraspecific competition between source tree and seedling (Jensen and Nielsen 1986). Rodents tend to scatter hoard, whereby acorns are cached in multiple numbers per caching site, which results in clusters of oak seedlings.

Scatter hoarding by squirrels (Sciurus spp.) prevents other seed predators from scavenging available acorn supplies, while the act of burial is beneficial to seedling establishment (Smith and Follmer 1972). However, squirrels tend to bury their acorns within the forest as opposed to open sites. Jensen (1982) found a direct correlation between rodent population size and mast production in oak-beech forests. The increase in population size implies a substantial amount of seed consumption, but would also result in increased scatter hoarding, increasing the chances of seedling production.

Johnson and Krinard (1985) state that rodent consumption of direct-seeded acorns can be disastrous. However, acorn consumption by rodents decreased as size of forest openings increased, up to approximately 0.8 ha, after which rodent consumption decreased dramatically (Johnson 1981). This correlation was attributed to increased predation of rodents by raptors in larger openings. The fields of our study were of comparable size to fields found to be free of rodent predation (Johnson 1981). This supported our belief that the blue jay was primarily responsible for acorn placement within our fields.

Methods

Three abandoned hayfields located on Keaton Tower Road on NNWR, and one older, abandoned hayfield located on a private landholding, the Arnold Tract, off the Sessums Road near the Noxubee-Oktibbeha County lines in central Mississippi were sampled to characterize and quantify hardwood regeneration. Field size on NNWR was 0.3, 0.75, and 1.1 ha, while the Arnold Tract was 5.1 ha. Circular plots (0.004 ha) were placed within the fields using a systematic grid sample with distances between plots and lines ranging from 10x10 m to 20x10 m, respectively, on the NNWR fields and 60.4x60.4 m on the Arnold Tract.

Species-specific measurements taken within the plots included total number of stems by origin class, sprout or seedling, and by height class, < 30 cm or > 30 cm. Each plot was subsequently divided into four quadrants based on cardinal points. Within each quadrant, one dominant red oak and one dominant sweetgum (*Liquidambar styraciflua* L.), if present, was measured. These stems were categorized by stem origin (sprout or seedling) and, if a sprout, the total number of sprouts per stump was recorded. Total height (cm) and root collar diameter (mm) 2.54 cm aboveground were also measured. Data were analyzed using ANOVA and significance was indicated at the 0.05 level by the F-test.

Mature cherrybark oaks that were deemed to be capable of producing acorns and serve as a possible seed source were located within the forest to a distance of 61 m from each NNWR field edge. These trees were classified with respect to dbh and mapped according to distance and bearing from a fixed point.

In addition, on the NNWR fields tree stems and rootstocks were aged in 1990-- 1 year after field measurements were taken--in an attempt to determine past history of oak establishment. Also, NNWR records were studied to reconstruct field history. Where information was scanty, NNWR personnel provided missing information. The three fields on the NNWR were cut for hay until 1986 and were then mowed and/or burned through late winter 1988, after which natural succession was allowed to occur. According to NNWR personnel, the fields were in hay production for at least the previous 10 years and, more than likely, for the previous 20 years prior to abandonment.

Results And Discussion

Stems from all three fields on the NNWR were 2 years old and dated back to the time when mowing and/or burning were excluded, and the stand was allowed to develop naturally (Table 1). The rootstocks, however, were variable in age and ranged from 5-10 years old. One limiting aspect of oak seedling development is slow initial height growth that prevents oaks from competing on an equal basis with other hardwood species. While continual mowing of hay prevented stem development from occurring other than annually, the rootstocks were allowed to grow and cumulatively increase food reserves. When the stems were no longer mowed the abundant food reserves of the rootstock allowed an aggressive stem to develop, which, in the case of the oaks has allowed them to be competitive with other woody stems. In an oak stand development study, Aust et al. (1985) reported that 78 percent of stands with a high percentage of oak had some form of disturbance that allowed development of sprout origin stems enabling the oak to compete on a more equatable basis. Ninety-four percent of the oak stems were of sprout-origin.

Table 1. Age, in years, of oak stems and rootstocks, from abandoned fields on the Noxubee National Wildlife Refuge, MS, spring 1990.

Field	Species[1]	Rootstock age	Stem age
		----- (yr) -----	
2	CBO 1	5	2
	CBO 2	5	2
	CBO 3	8	2
3	CBO 1	6	2
	CBO 2	–	2
	CBO 3	–	2
18	CBO 1	–	1 [2]
	CBO 2	–	2
	CBO 3	10	2

[1] CBO = cherrybark oak.
[2] Stem aged in 1989.

Continual mowing has probably led to a greater number of oak stems on the NNWR fields due to the prolonged caching efforts of blue jays and rodents. In a natural disturbance (e.g., a blow-down) there would be a far more limited period of time for acorn placement.

Heights of sweetgum stems were significantly greater ($P = 0.05$) than red oaks in field 18 and field 3, with no significant difference in heights in field 2 (Table 2). Root collar diameter was also significantly greater for sweetgum in field 18 and field 3, and significantly greater at the 0.10 level in field 2. Similar trends occurred with relation to the total number of sprouts per stump, with sweetgum having a significantly greater number of sprouts in field 18 and field 3, and a significant difference at the 0.10 level in field 2.

On the Arnold tract the only dominant trees were oak species. Therefore, no comparison between sweetgum and oaks were made.

Cherrybark oak acorns from a different study (unpublished data) were raded into an acceptable size class for planting. Twenty acorns randomly elected from this particular size class averaged 2.2 g in wet weight, 14.1 ı in length, and 15.8 mm in width. These averages fell within the range f preferred acorns (Bossema 1979, Darley-Hill and Johnson 1981). There e no data available for size characteristics of other red oak species, g., water (Q. nigra L.) and willow oak, found within the fields. Based ı personal observation, water and cherrybark oaks are somewhat similar in ze with willow oak being smaller than the afore mentioned oak species. ır observations suggest there is selective preference by foraging birds r cherrybark oak acorns due to the ease with which the shell can be brok- ı open. Perhaps this selective preference coupled with the desirable size aracteristics of cherrybark oak may explain the higher numbers of that rticular red oak species in the NNWR fields.

Table 2. Comparisons of height (HT), root collar diameter (RC), and number of sprouts per stump (SP) for stems of red oak (RO) and sweetgum (SG) on abandoned fields on the Noxubee National Wildlife Refuge, MS.

Stem[1] characteristic	Field 18[2]	Field 2	Field 3
RO HT (cm)	51.1a	75.5a	90.2a
SG HT	67.5b	86.7a	119.8b
RO RC (mm)	5.2a	7.2a[3]	8.3a
SG RC	6.4b	8.5a	11.5b
RO SP	2.9a	2.5a[3]	2.0a
SG SP	4.8b	3.1a	4.4b

[1] RO = red oaks; includes cherrybark, water, and willow.

[2] Means within a field and a characteristic not followed by the same letter are significantly different at P = 0.05, according to the F-test.

[3] No significant difference at the 0.05 level, but significantly different at the 0.10 level.

Analysis of the number of oak stems per plot suggested a trend based on lge effect for the larger fields, i.e., fields 3, 18, and the Arnold act, which are approximately 0.8 ha in size and larger. More oaks were

found in plots 10-12 m from the forest edge, with numbers decreasing as plots progressed towards the center of the fields. However, these trends appeared not to be related to oak trees around the perimeter of the fields owing to their low numbers and random occurrence. The more open nature of the fields may enhance the ability of predators to prey on rodents (Johnson 1981) and, possibly, blue jays that venture out into the open. It is highly likely that caching would occur nearer to the forest edge to provide an avenue of escape for the caching species. Johnson and Krinard (1985) noted that raptor predation may serve to prevent rodent acorn consumption in openings 0.8 ha in size and larger. Field 2, which is 0.3 ha in size, does not follow as obvious a trend of more oaks along edge plots. This field is longer than wide, however, and thus may have more edge. On the Arnold Tract there is an island of trees within the field that is older than the regenerating species occupying a majority of the field. The trees within this isolated island are not of seed-bearing age and, therefore, cannot serve as a seed source for the field. This island of trees may provide an edge effect as there is a high number of oaks occurring within a plot located next to the older clump of trees. The occurrence of oak seedlings within the field is not associated with oak seed trees, again emphasizing the role of an outside agent in establishment of oak regeneration.

The NNWR fields had a significantly higher number of oak sprouts in both height classes, < and > 30 cm than oak seedlings. Annual mowing apparently led to a greater number of oak stems in the fields. Perhaps the annual suppression of vegetative growth allowed continual acorn caching by blue jays and, possibly, rodents. Mowing resulted in coppice development of oak stems that are better able to compete. Stands dominated by oak will, in all probability, develop on these abandoned fields.

The sweetgum on field 18 had a significantly greater number of sprouts in both height classes than sweetgum seedlings. There was no significant difference between sweetgum sprouts and seedlings of both height classes on the other NNWR fields and the Arnold Tract (Table 3).

The natural development of these fields to forest will probably follow the trends Clatterbuck and Hodges (1988) found in mixed cherrybark oak-sweetgum stands. If so, sweetgum will dominate the stand through the first 20 years of stand development, with cherrybark oak gradually overtopping the sweetgum and becoming the dominant component of the overstory. That study dealt mainly with seedling-origin stems of both species, and it is conjecture at this point to surmise that the oak sprouts will overtop those of sweetgum earlier than in seedling-origin stands. Sweetgum sprouts may exhibit a decreased annual height growth increment at an earlier age than sweetgum seedlings while, conversely, oak sprouts may exhibit a greater annual height growth increment than oak seedlings. The interplay of these factors would result in oak overtopping the sweetgum earlier than reported by Clatterbuck and Hodges (1988).

Another factor indicating blue jays to have been the main means of oak establishment in the fields is the fact that there were no clustering of oak stems from multiple acorn caching by rodents. Clustering would have been apparent in the inspection of seedlings for origin class (seedling or sprouts).

Table 3. Numbers of red oak (RO) and sweetgum (SG) stems by origin class, i.e., seedling (SD) or sprout (SP), and height class for abandoned fields on the Noxubee National Wildlife Refuge, MS, and the Arnold Tract, MS.

Field	Species	Origin class	No. stems/ht < 30 cm	Class > 30 cm
18	RO [1]	SD	130a [2]	24a
	RO	SP	998b	1153b
	SG	SD	147a	7a
	SG	SP	470b	1655b
2	RO	SD	128a	72a
	RO	SP	864b	1656b
	SG	SD	8a	–
	SG	SP	20a	226
3	RO	SD	8a	–
	RO	SP	294b	1863
	SG	SD	3a	–
	SG	SP	11a	166
Arnold Tract	RO	SD	7a	322a
	RO	SP	7a	207a
	SG	SD	7a	343a
	SG	SP	7a	165a

[1] RO = red oaks; includes cherrybark, water and willow.

[2] Means within a field and a characteristic not followed by the same letter are significantly different at P = 0.05, intraspecifically, according to the F-test.

The only other hard mast species, other than oaks, that occurred within the fields was hickory (Carya spp.). Hickory was only located in plots along the edge of the forest in field 18. Because of size, hickory nuts were probably carried into the field by squirrels. The other hardwood species found within these fields, not classified as light-seeded, were Mexican plum (Prunus mexicana Wats.), common persimmon (Diospyros virginiana L.), honeylocust (Gleditsia triacanthos L.), black cherry (Prunus serotina Ehrh.), shining sumac (Rhus copallina L.), and vaccinium (Vaccinium spp.). These woody plant species serve as wildlife food (Hall 1977) and, in all likelihood were placed on these fields through animal defecation. Field 18 contained all of these woody plant species, while the other fields contained several of these species.

In conclusion, it is apparent that forest succession has been influenced to a large degree by occurrence of a natural phenomenon, i.e., the propensity of blue jays to cache acorns and, also, man's cultural activities. Jays were able to store acorns in a "seed bank" over a long time period due to annual mowing, which kept the fields in an arrested state of development. Mowing also allowed oak rootstocks to increase in size over time, permitting the formation of vigorous sprouts of high competitive ability. In all probability, these fields will regenerate to red oak dominated forests.

Acknowledgments

Contribution No. PS-7644 of the Mississippi Agricultural and Forestry Experiment Station. Authors thank James Burnette, Dave Smith and Jim Tisdale of the Noxubee National Wildlife Refuge, Mississippi, for their cooperation. Also, much gratitude to Drs. Dennis Cengel, Andy Ezell, George Hurst, Bob Karr and C. E. Watson for their critical review of this manuscript. Finally, thanks to student-workers Randy Bolton, Jason Thomas, Lance Prine, and Scott Barris.

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EFFECTS OF MORPHOLOGICAL GRADE ON FIELD PERFORMANCE OF CONTAINER-GROWN SOUTHERN PINE SEEDLINGS [1]

James P. Barnett [2]

Abstract. Container-grown loblolly (Pinus taeda L.), slash (P. elliottii Engelm.), shortleaf (P. echinata Mill.), and longleaf (P. palustris Mill.) pine seedlings were graded into three distinct morphological grades for field planting early in May and in September 1983 to determine the effects of these grades on field survival and growth. Field performance, particularly growth, of the larger stock was generally best. The difference in response of the larger seedlings was greatest when conditions of stress were encountered after field planting, and grade affected growth more than it affected survival.

Introduction

Wakeley (1954) established the value of grouping nursery-grown southern pine seedlings into morphological grades. Field survival and growth were related to morphological properties. Considerable evidence has been developed about differences in the characteristics and performance of bare-root and container seedlings (Goodwin 1976, Barnett and Brissette 1986, South and Barnett 1986, Boyer 1989, Brissette and Barnett 1989). The reason for the differences in early establishment of bare-root and container stock relates to the condition of the root systems when the seedlings are field planted. Whereas a large portion of the root system of bare-root seedlings is lost during lifting from nursery beds, the root system of container seedlings remains intact during transplanting. Planting an intact root system results in less transplanting shock and higher initial survival and growth, particularly when conditions following planting are stressful.

It has become obvious, with the differences in root systems due to seedling type, that the morphological grades established for bare-root stock are not applicable to container stock (Barnett and Brissette 1986). The relative importance of differences in seedling morphology of container stock has also been questioned. The objective of this study was to determine whether different morphological grades of container-grown southern seedlings showed differences in field survival and growth.

Methodology

Loblolly (Pinus taeda L.), slash (P. elliottii Engelm.), shortleaf (P. echinata Mill.), and longleaf (P. palustris Mill.) pine seedlings were graded into three morphological groups for field planting in May and September 1983. The three groups or grades of seedlings were obtained by selecting individuals from the range

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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variation present within total crop. All seedlings were of the same age (about 12 weeks from seed), were subject to the same cultural practices, and were grown in the same medium and type of container.

The established specifications of the three seedling grades do not necessarily reflect the current belief as to what constitute optimum grades, but they do represent a range in characteristics of stock being produced when this study was conducted. Species and season of the year markedly affect the seedling development obtained. The grades used are shown in Table

Table 1. Grades of container-grown seedlings used in the study.

Grade	Slash	Loblolly	Shortleaf	Longleaf
	---------- ht/inches (mm)		-----------	Diameter (mm)
1	9-10 (240)	8-9 (215)	7-8 (190)	5.0-5.5
2	7-8 (190)	6-7 (165)	5-6 (140)	4.0-4.5
3	5-6 (140)	4-5 (115)	3-4 (090)	3.0-3.5

Bare-root nursery seedlings were field planted in late March to provide growth comparison with the May planting of container seedlings, but they were not included in the statistical comparisons.

Todd's Planter Flats (3.8 by 12.7 cm) were used to produce the seedlings. A 1:1 mix of peat and vermiculite was the potting medium, and all stock was fertilized with Peters' 20-19-18 NPK. Seeds collected from local lots were used in the study. Enough stratified loblolly and shortleaf pine seeds and unstratified slash and longleaf pine seeds were sown (about 12 weeks prior to planting) with two seedlings that germinants were available to transplant into cavities where seeds failed to germinate. The guidelines developed by Pawuk (1982) for transplanting germinants were followed. Seedlings were grown without blocking because of space limitations and lack of environmental variation in the greenhouse.

Field plots were established on the Johnson Tract of the Palustris Experimental Forest in Rapides Parish, Louisiana. The site is typical of clearcut forest land that was prepared by chopping following cutting. The area was also control burned in the winter prior to planting to minimize differences in competition caused by regrowth of competing vegetation. The topography is very gently rolling, affording adequate surface drainage.

Plots for each species combination (two planting dates by three seedling grades) consisted of six 6-seedling rows (36 seedlings) planted at a 1.83- by 1.83-m spacing. The container seedlings were hand planted with a locally fabricated punch. Bare-root stock were planted with a dibble. A randomized block split-plot design consisted of four 36-seedling plots. Each 36-seedling plot was used in the field portion of the study. Major

plots were by date of planting (May or September), and minor plots were by seedling grade. Separate analyses of variance were conducted for species, survival, and height determinations.

Four 5-seedling replications per seedling grade were characterized at the time of planting by determining top height, stem (groundline) diameter, and stem and shoot dry weight. Survival percentage was measured about 2 months after planting, and survival and heights (to the tip of the bud) were measured in the fall and again in the fall of the succeeding year. Heights were measured to the nearest 3.0 cm; groundline diameters were measured with a caliper to the nearest 2.5 mm.

Results And Discussion

Seedling Characteristics at Planting

A sample of seedlings from each species-grade classification was used to characterize the stock at time of planting. Although seedling quality was comparable between May and September planting dates, there were some important differences (Table 2). The most obvious difference was in top weight. Seedlings produced for the September crop were heavier than those for the May crop--mainly because of heavier tops. This difference primarily reflects better growing conditions for the September crop. Grading seedlings by height (and diameter for longleaf pine) generally showed associated differences in the other parameters as well. Root weight was less related to height than any of the other variables measured.

Field Performance

Because the bare-root stock that was planted for comparative purposes was not grown from the same seed source, it was not included in any statistical analyses. However, it is apparent that the survival of container stock, regardless of grade, equaled that of bare-root stock (Table 3). As expected, because bare-root stock was 1 year older from seed, the size of container stock was smaller, except for shortleaf pine.

The differences in time of planting of the container stock had a marked effect on seedling survival. Seedlings planted in mid-September were obviously under slight moisture stress; average survival for all species was 98 percent and there were no differences among grades. Survival of seedlings planted in mid-May was considerably lower, averaging 76, 82, and 71 percent for longleaf, loblolly, and slash pine, respectively.

Morphological grade had no statistically significant effect on field survival, but trends did occur with longleaf and slash pine (Table 3). In these two species, seedlings categorized as grade 3 survived less well, with average survival more than 10 percent lower than for the average of grades 1 and 2.

Generally, seedling size was affected by morphological size for both planting dates. Grade 3 seedlings of longleaf pine had smaller root-collar diameters than either grade 1 or grade 2 stock when planted in May (Table 3). In the later field planting, only grade 3 stock differed from grade 1 stock. In loblolly and slash pine seedlings, heights of grade 2 and 3

Table 2. Characteristics of seedlings by species and grade at the time of field planting.

Species	Grade	May planting				September planting			
		Ht.	Dia.	Weight top	Weight root	Ht.	Dia.	Weight top	Weight root
		-- (mm) --		-- (mg) --		--- (mm) ---		--- (mg) ---	
Longleaf	1	- [1]	5.2	1,079	438	-	5.5	1,868	485
	2	-	4.0	1,141	280	-	4.4	1,582	264
	3	-	3.3	997	193	-	3.7	1,459	217
Slash	1	237	3.5	1,113	315	244	3.4	1,528	284
	2	180	3.2	907	327	197	3.2	1,306	306
	3	132	3.2	852	337	142	3.0	1,073	317
Loblolly	1	234	2.9	1,058	246	221	3.0	1,442	251
	2	184	2.8	790	229	167	2.8	1,154	228
	3	141	2.7	716	235	121	2.9	1,126	276
Shortleaf	1	- [2]	-	-	-	202	2.9	1,229	255
	2	-	-	-	-	145	2.8	1,062	248
	3	-	-	-	-	100	2.6	844	222

[1] In this species, no early epicotyl growth occurs.

[2] Shortleaf pine seedlings were not produced for the May field planting.

eedlings were less than grade 1 seedlings. In the September planting, rade affected size in the field for longleaf, slash, and shortleaf pine, ut not for loblolly pine. Generally, grade 1 seedling size was larger han grade 2 and 3 size.

Conclusions

The different seedling grades used in this study did affect field per- ormance, particularly growth; larger stock generally performed best. The ifference in response of the better grades (larger seedlings) was greatest hen conditions of stress were encountered after field planting. There- ore, there are distinct advantages in developing morphological standards or container stock, but field growth seems more closely related to seed- ing grade than does survival. Incremental growth is another meaningful arameter to use in evaluating performance; however, size of newly planted eedlings was not measured. Therefore, covariate analysis based on incre- ental growth was not feasible. It is important to realize that the grades

used in this study are not necessarily the ones that should be recommended for typical reforestation sites. Additional studies will be needed to develop the seedling morphology-field performance relationships necessary to establish general morphological grades.

Table 3. Field survival and seedling size data measured in February 1984 (1+ years after planting).

Species	Stock type	May planting		September planting	
		Survival	Size[1]	Survival	Size
		- percent -		- percent -	
Longleaf	Bare root	79	1.93	--	--
	Container 1	79a	1.17a	96a	1.52a
	Container 2	84a	1.14a	99a	1.40a
	Container 3	71a	1.02b	96a	1.32b
Loblolly	Bare root	59	4.75	--	--
	Container 1	81a	4.57a	98a	3.18a
	Container 2	78a	3.94b	100a	3.10a
	Container 3	88a	3.91b	99a	3.15a
Slash	Bare root	56	6.32	--	--
	Container 1	78a	4.88a	97a	4.01a
	Container 2	72a	4.24b	99a	3.81b
	Container 3	63a	3.96b	98a	3.81b
Shortleaf	Bare root	74	3.07	--	--
	Container 1	-- [2]	--	97a	3.81a
	Container 2	--	--	98a	3.53b
	Container 3	--	--	97a	3.23c

[1] Size measurements are expressed in cm for longleaf pine root-collar diameters and in ft for loblolly, slash, and shortleaf height. Treatment means within species grades followed by different letters are significantly different at the 0.05 level.

[2] No shortleaf pine container stock was produced for the first field planting.

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EFFECTS OF PLANT GROWTH REGULATORS ON LOBLOLLY PINE SEEDLING DEVELOPMENT AND FIELD PERFORMANCE [1]

John I. Blake and David B. South [2]

Abstract. Four plant growth regulators (ancymidol, benzyladenine, ethrel, and flurprimidol) were compared with two top pruning treatments at a nursery near Byron, Georgia. Chemical applications applied in August were generally more effective in reducing growth than were September applications. Among the growth regulators tested, only benzyladenine applied in August appeared to reduced height growth. A single top pruning in early August substantially increased average height growth to the point where average seedling heights in December were not reduced. The treatments were lifted in January and deep-planted in mid-March on an old-field near Auburn, Alabama. First-year survival was excellent (> 92 percent) despite the dry spring. None of the treatments were significantly different from the control in terms of survival or height growth in the field.

Introduction

Under favorable growing conditions, loblolly pine (Pinus taeda L.) seedlings in bare-root nurseries often initiate a rapid phase of height growth during August which usually terminates in late September as photoperiod decreases. Controlling this phase of height growth can be an important factor in culturing seedlings for planting on reforestation sites in the southern region. Tall loblolly pine seedlings (> 25 cm) are often considered undesirable for tree planting (Tuttle et al., 1987, 1988). Not only do tall seedlings impede hand planting operations, but they may also suffer more from exposure to desiccating environments and drought (Dierauf 1976; Carlson and Miller 1988).

Current methods for reducing seedling heights include top pruning (Dierauf 1976), root pruning (Tanaka et al., 1976; Miller et al., 1985), and withholding irrigation (Stransky and Wilson 1964; Hennessey and Dougherty 1984). To be effective, top pruning requires removal of a significant portion of existing shoot followed by several repeated cuttings to prevent new shoot initiation from axial buds from exceeding the original growth. Root pruning or wrenching during July and August has obtained widespread acceptance, but it appears to be more easily applied in sandy soils. Although inducing moisture stress by withholding irrigation can be effective, it is not always feasible due to high rainfall patterns in the southern coastal region.

Plant growth regulators are widely used in ornamental plant production to control development of plant size, leaf shedding, growth cessation, and other characteristics (Geissbuehler et al., 1987). Growth regulators can be a cost-effective approach in creating a uniform crop appearance for marketing purposes,

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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and for creating other characteristics which are desireable for handling and shipping. Such compounds have been tested on conifers for controlling growth in ornamental landscapes (Backhaus et al., 1976), seed orchards (Hare 1982, 1984), nursery seedlings (Plank 1939; Maki et al., 1946; Weston et al., 1980; Wheeler 1987), and christmas trees (Little 1984). Many of these chemicals have been reported to reduce growth, but with resulting detrimental effects either in terms of appearance or subsequent growth (Ross et al., 1983). Additionally, chemicals like paclobutrazol (Wheeler 1987), while they are highly effective in controlling heights, are very persistent in the soil. This characteristic limits their usefulness in bare-root nurseries. The objective of the study was to determine if selected growth regulator treatments could reduce late summer height growth in loblolly pine seedlings, and would these treatments adversely affect subsequent field performance.

Methods

The experiment was installed on July 28, 1987, using unimproved loblolly pine at the Georgia Forestry Commission Nursery near Byron, Georgia. The study was laid out as a randomized complete block design with four blocks. Treatments included four chemicals (Table 1) which were applied at one of two application times (early August or early September). Plots were 1-m long by 1.4-m wide with a 0.5-m buffer strip between plots. Within each plot, 18 were selected for repeated height measurements. Three seedlings from each of the center six drill rows nearest a line placed across the plot were tagged with numbered, water-proof tape. Initial heights were measured on these seedlings at the time of treatment and every month thereafter until December.

Table 1. Chemical treatments and rates (two applications made to each plot to equal the total amount applied)

Common name (Trade name)	Concentration[1] low	Concentration[1] high	Rate/application low	Rate/application high	Total applied low	Total applied high
	-- mg/L ai --		-- g/ha ai --		product/ha	
Flurprimidol (Cutlass 50W)	0.5	1.0	0.115	0.23	0.46 g	1.84 g
Ancymidol (A-Rest 0.0264%)	50.0	100.0	11.5	23.0	87.4 l	174.8 l
Ethrel (Florel 4%)	1000.0	2000.0	230.0	460.0	11.5 l	23.0 l
Benzyladenine (Pro-Shear 2%)	500.0	1000.0	115.0	230.0	11.5 l	23.0 l

[1]Each solution contained 0.05 percent Armox C-12 wetting agent.

Each chemical treatment within a monthly period was applied twice in two separate broadcast spray applications, 7 to 9 days apart. The early August applications were made on July 28th and August 8th. The September applications were made on the 4th and 11th. The solution was applied through 3-LP8003 flat fan nozzles at a pressure of 1330 kPa and a volume of 230 L/ha. Seedlings within the top pruning treatment were clipped to a uniform height of 15 cm in late July for the August treatment, and 20 cm in early September for the September treatment. Approximately 70 percent of the seedlings in the top-pruning treatment were clipped in late-July, and 40 percent during the early September top pruning.

The ancymidol, benzyladenine, top pruning and the control treatments were lifted for outplanting and size measurements on January 6, 1988. The diameter, shoot and root dry weights were measured on the tagged seedlings. Another 25 seedlings per plot were placed in plastic bags and stored at temperatures ranging from 3-5°C until mid-March. The planting site was situated 10 km north of Auburn, Alabama, on an abandoned agricultural field dominated by broomsedge (Andropogon spp.). The surface soil texture is a clay loam. The seedlings were deep-planted (the root-collar was placed approximately 9 cm below ground level) with shovels. Survival and height growth of each treatment was evaluated in November 1988 and again in April 1990. The data was subject to an analysis of variance and, when appropriate, means were compared using Duncan's new multiple range test (Steel and Torrie 1960).

Results

Total heights at the end of the season were similar among all treatments (Table 2). The extreme variability in seedling development both within plots and between blocks likely obscured treatment effects. Differences in height growth were easier to detect than differences among final heights.

Of the treatments applied in August, only the high rate of benzyladenine significantly reduced height growth during August (Table 2). None of the treatments reduced growth during September when compared with the control. However, when applied in August, the top pruning, ancymidol, and ethrel treatments resulted in increased growth during September. Chemicals applied in early September were generally ineffective in reducing subsequent height growth. The single top pruning applied in August increased average height growth during September. In contrast, seedlings top pruned in early September did not grow more than the controls. In general, height growth for all treatments was largely completed by the end of September.

No significant treatment effects were associated with either shoot length (Table 2) or diameter (Table 3). However, the height/diameter ratio was reduced by the August applications of benzyladenine. Similarly, root and shoot dry weights were unaffected by any of the treatments compared with the control (Table 3). None of the treatments improved the shoot/root ratio.

Table 2. Height growth during August and September, and the final height in December for tagged seedlings of each treatment

Treatment	Product rate	Date	Height growth August	Height growth September	December height[1]
	ha	month	mm		
Control			38.1 a	12.7 def	214
Top prune	----	August	23.0 ab	48.8 a	219
Top prune	----	September	----	12.0 ef	209
Ancymidol	87.4 l	August	38.2 a	19.5 bcde	231
Ancymidol	87.4 l	September	----	16.3 cdef	229
Ancymidol	174.8 l	August	38.4 a	26.3 bc	241
Ancymidol	174.8 l	September	----	19.5 bcd	222
Benzyladenine	11.5 l	August	22.0 ab	15.6 cdef	211
Benzyladenine	11.5 l	September	----	21.5 bcde	211
Benzyladenine	23.0 l	August	18.1 b	0.7 f	191
Benzyladenine	23.0 l	September	----	15.7 cdef	213
Etherl	11.5 l	August	33.6 ab	25.4 bcd	222
Etherl	11.5 l	September	----	17.8 cdef	223
Etherl	23.0 l	August	28.6 ab	30.7 b	208
Etherl	23.0 l	September	----	21.1 bcde	213
Flurprimidol	0.92 g	August	37.9 a	14.1 cdef	225
Flurprimidol	0.92 g	September	----	18.0 bcdef	217
Flurprimidol	1.84 g	August	29.0 ab	21.8 bcde	224
Flurprimidol	1.84 g	September	----	23.9 bcde	229

[1]No significant treatment effects were found for height in December (F-test = 0.5840). Means followed by the same letter are not significantly different at the 5 percent level of probability (as determined by Duncan's new multiple range test).

Survival among treatments (Table 4) was very high despite the 10-week storage period and the lack of rainfall for several weeks following planting. The high survival was due in part to planting the seedlings 8.8 cm deeper than the level at which they were grown in the nursery. Height growth among treatments in the field was very similar. We observed no visible evidence that the abnormal shoot growth effects (multiple buds and shorter needles) from benzyladenine persisted after planting when seedling evaluations were made in the fall of 1988.

Table 3. Average diameter, height/diameter ratio, shoot weight, root weight, and shoot/root ratio for tagged seedlings lifted on 6 January 1988.

Treatment	Rate	Time[1]	Diameter	Height / diameter	Dry weight shoot	Dry weight root	Shoot / root
	L/ha	month	-- mm --	- mm/mm -	---- g ----		-g/g-
Control			4.05	53a	2.61	1.33	1.94c
Top prune	---	August	4.10	54a	2.54	1.12	2.27abc
Top prune	---	September	4.19	50ab	2.61	1.37	1.95c
Ancymidol	87.4	August	4.69	49ab	3.68	1.61	2.29abc
Ancymidol	87.4	September	4.39	52a	3.06	1.28	2.39ab
Ancymidol	174.8	August	4.48	54a	3.25	1.37	2.36ab
Ancymidol	174.8	September	4.36	50ab	3.15	1.39	2.25abc
Benzyladenine	11.5	August	4.58	46b	3.24	1.51	2.16abc
Benzyladenine	11.5	September	4.12	53a	2.82	1.09	2.53a
Benzyladenine	23.0	August	4.28	45b	2.57	1.27	2.01bc
Benzyladenine	23.0	September	3.95	53a	2.90	1.41	2.02bc

[1] Significant ($p < 0.05$) orthogonal contrasts within treatments between application times are indicated (*). Rate effects within application times were not compared. No significant treatment effects were found for diameter (F-test = 0.1987), shoot weight (F-test = 0.1681), or root weight (F-tests = 0.1925).

Discussion

The results from the single top pruning are consistent with previous research on this practice (Dierauf 1976; Dierauf and Olinger 1982; Barnett 1984; Mexal and Fisher 1984; Duryea 1990). A single, early top pruning tends to stimulate height growth in the nursery. As a result, removal of a significant portion of the shoot and repeated prunings are needed to reduce total height. A loss in growth from the taller seedlings that were pruned resulted in a more uniform crop. When conditions for survival are less than optimum, there appears to be a net benefit in terms of field survival (Dierauf 1976; Dierauf and Olinger 1982).

It appears that certain chemical growth regulators may be effective in controlling height growth in southern pine nurseries. In this preliminary study, benzyladenine was effective in reducing height growth when applied in August. We observed no detrimental effects on subsequent seedling performance from the 11.5 L/ha rate. However, at higher rates, benzyladenine can produce undesirable effects, such as abnormal bud development, inhibition of secondary needle extension, delayed bud break, and reduced root development (data not shown). Consequently, the rate and timing of application must be carefully controlled in order to achieved a net beneficial effect. Low to moderate rates of benzyladenine (up to 11.5 L/ha) applied

after secondary needle elongation is nearly complete is worthy of further study. It may also be desirable to combine this treatment with top pruning.

Table 4. Initial post-planting heights, height growth, and survival for seedlings that were planted in mid-March 1988. Growth and survival were evaluated in April 1990.

Treatment	Rate	Time[1]	Initial height	Height growth	Survival
	L/ha	month	------ cm	------	-- % --
Control			12.6	108	95
Top prune	----	August	14.6	98	89*
Top prune	----	September	14.3	106	98*
Ancymidol	87.4	August	15.8	105	93
Ancymidol	87.4	September	15.1	105	94
Ancymidol	174.8	August	16.4	107	94
Ancymidol	174.8	September	14.9	107	93
Benzyladenine	11.5	August	13.7	108	95
Benzyladenine	11.5	September	14.3	106	95
Benzyladenine	23.0	August	11.8	107	93
Benzyladenine	23.0	September	12.7	101	93

[1] Significant ($p < 0.05$) orthogonal contrasts within treatments between application times are indicated (*). Rate effects within application times were not compared. No significant treatment effects were found for initial height (F-test = 0.0788), growth (F-test = 0.6545), or survival (F-test = 0.6873).

Acknowledgments

Appreciation to Hans Williams, Robert Childree, and Nancy Stumpff for assistance in the installation and measurement of individual experiments; and to Dr. Robert Hare for helpful suggestions.

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NITROGEN FERTILIZATION AFFECTS THE PARTITIONING OF DRY MATTER GROWTH BETWEEN SHOOTS AND ROOTS OF LOBLOLLY PINE NURSERY STOCK [1]

John C. Brissette and Allan E. Tiarks [2]

Abstract. Normal nursery culture includes fertilizing with nitrogen (N) to promote seedling growth and development. Previous research suggested that supplying N in several applications at an increasing rate results in seedlings with a smaller average shoot-to-root ratio than the conventional method of equal-rate applications. This study tested the hypothesis that the increasing-rate technique partitions more growth to the roots than does the constant-rate method. Allometry was used to study partitioning of dry matter growth between the shoots and roots. The results did not support the hypothesis; the method of N application did not affect partitioning. However, the growth of the shoots and roots was altered by the total amount of N applied. As total N increased from 0 to 120 kg N/ha, there were linear increases in both shoot and root dry weight at lifting, with the effect being greatest on the shoots.

Introduction

Nursery soil fertility is an important factor affecting seedling morphology, physiology, and field performance. Of the nutrients applied in fertilizers, nitrogen (N) is particularly important because of its role in protein and chlorophyll synthesis, and thus, in seedling growth and development. Plants can take up N in two ionic forms, nitrate (NO_3^-) and ammonium (NH_4^+), both of which are available in soils. However, N availability depends on the decomposition of organic matter, which is greatly affected by soil moisture and temperature. The NH_4^+ ion is the primary ion released by soil organisms. The negatively charged clays in soil retard leaching of NH_4^+ until it is taken up by plant roots, used by soil microbes, or converted to NO_3^- by bacteria. The NO_3^- form can be used by plants but moves with soil water and readily leaches from the root zone.

Because the soil environment affects nutrient mobility and availability, N must be resupplied frequently during the rapid-growth phase in the nursery if high-quality seedlings are to be produced. The N for postgermination applications is usually supplied in topdressings with fertilizers in a granular or prilled form. The total amount of N applied to nursery seedlings and the number of applications required to supply that total depend on a number of factors, including physical and chemical soil properties, the

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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e fertilizer formulation used. While general guidelines are available r the southern pines (May 1985), specific recommendations must be made on nursery basis and, in some nurseries, on a compartment basis.

Increasing the total amount of applied N increases the dry matter of th shoots and roots. Typically, shoot dry weight increases more than ot dry weight, so that as total applied N increases so does the shoot- -root ratio of southern pine seedlings (Fowells and Krauss 1959, McGee 63, Switzer and Nelson 1963). However, that general trend does not al- ys apply. In research with shortleaf pine (Pinus echinata Mill.), there s a significant linear increase in root volume as N increased from 55 to 0 kg/ha, but the highest N rate produced shorter, larger diameter seedl- gs than did the lower rates (Brissette and Carlson 1987).

A recent innovation in topdressing with N is applying the fertilizer at increasing rate as the seedlings grow, rather than making several equal plications. Timmer and Armstrong (1987) showed that the morphology of ntainer red pine (P. resinosa Ait.) could be altered to obtain a better lance between shoots and roots if N is applied in increasing increments ther than in equal increments. They applied N at exponentially increas- g rates so that the amount of N supplied increased as the seedlings grew. issette et al. (1989) tried this technique with bare-root shortleaf pine d found that the method of applying 90 kg N/ha interacted with family en three half-sib families were tested. One family showed few morpho- gical effects resulting from the method of N application, but it did have eater root growth potential (RGP) under the increasing-rate regime. The plication method affected the root morphology of the other two families, t only one showed increased RGP from the increasing-rate treatment.

The distribution of dry matter between shoot and roots is often expres- d as the shoot-to-root ratio. Ledig and Perry (1966) pointed out that e shoot-to-root ratio changes as plants grow and is a poor criterion for mparing plants of different sizes. However, they did show that an ap- opriate comparison can be made using the allometric equation described by xley (1932). Allometry is the study of relative growth. During much of e growing season, shoot and root growth of seedlings is logarithmic, and e ratio of the relative growth rates is a constant. That constant is ap- oximated by the simple linear regression coefficient of the logarithmic lationship between some measure of these two organs. This relationship relative growth rates is not strictly linear, especially during germin- ion and late in the growing season, when shoot growth slows before root owth does. However, treatment effects on relative growth rates can be amined by studying changes in the allometric equation. For example, ven a number of measurements over a growing season, the relationship be- een shoot or root dry weight and total plant dry weight can be shown by e allometric equation:

$$\ln \text{(shoot or root dry weight)} = a + k \times \ln \text{(total dry weight)} \qquad [1]$$

us, if different treatments are applied during the growing season, the

regression coefficients of the allometric equations can be compared to measure treatment effects on growth partitioning to different organs. Ledig and others (1970) used allometry to examine the effects of light and moisture levels on the partitioning of dry matter between shoots and roots in loblolly pine (P. taeda L.) seedlings. Bongarten and Teskey (1987) used allometry to show that water-stressed loblolly pine seedlings from a number of seed sources allocated more dry matter to the roots than to the shoots as compared with well-watered control seedlings.

The objectives of this study were to: (1) determine the pattern of response of loblolly pine seedlings grown at Ashe Nursery in Mississippi to a range of total N fertilization; and (2) compare applying N at increasing rates with the conventional equal-rate method. This paper reports on how the treatments affected dry matter accumulated up to the time of lifting and the partitioning between shoots and roots during growth in the nursery.

Materials And Methods

The study was conducted at the United States Department of Agriculture Forest Service's W.W. Ashe Nursery in southern Mississippi using seedlings from a seed orchard source of south Mississippi loblolly pine. Seeds were sown in Compartment 7 of the nursery on April 19, 1989, using a vacuum drum precision seeder. The study was established 5 weeks after sowing, when the germinated seedlings had completely shed their seedcoats. Portions of four adjacent nursery beds were designated as blocks in a randomized complete-block experimental design. Each nursery bed was divided into ten 5-m plots. These 40 plots were the experimental units. Because seedbed density and N can interact in their effects on seedling attributes and performance, this study was laid out in an area with the most uniform density available. The density of each plot was determined on June 19, after germination was complete and the seedlings were established. The average seedbed density was estimated by counting the number of seedlings in randomly selected 30-cm segments in four drill rows.

Typically at Ashe Nursery, loblolly pine seedlings are topdressed with a total of about 76 kg N/ha from ammonium nitrate (NH_4NO_3), which contains 34 percent N. In this study five levels of total N were compared: 0, 30, 60, 90, and 120 kg/ha. Ammonium nitrate fertilizer was applied to the study plots either in four equal increments (the constant-rate method) or in greater amounts at each application (the increasing-rate method). Fertilizer application under both methods was at about 2-week intervals; the dates of application were May 24, June 6, June 20, and July 6, 1989. Application was with a Gandy™ Model 604 drop-type fertilizer spreader pulled behind a tractor.

The increasing rate-method required a different N application for each of the four N levels on each application date (the fifth level was 0 N). For a total of 30 kg/ha on the increasing-rate plots, N was applied at 3.75, 3.75, 7.50, and 15.00 kg/ha. For 60 kg/ha, the increasing-rate plots received N at 3.75, 11.25, 18.75, and 26.25 kg/ha. The increasing-rate plots at 90 kg/ha received 11.25, 18.75, 26.25, and 33.75 kg N/ha. For the highest rate of 120 kg N/ha, the increasing-rate plots received 18.75, 26.25, 33.75, and 41.25 kg/ha.

Other practices, such as root pruning, were done by nursery personnel and the seedlings were not top pruned. Seedling growth and development were followed during the growing season. Just before the first fertilizer application on May 24, a total of 204 seedlings were lifted from randomly selected locations in the study area for shoot and root dry weight measurements. Throughout the rest of the growing season, each plot was sampled by carefully hand-digging seedlings for dry weight measurements. Samples were taken on June 6, June 20, July 6, July 19, August 15, September 12, October 11, November 14, and when the study was lifted on January 9. When the seedlings were small they were uniform in size, and 10 seedlings per plot were carefully hand-dug for sampling. By mid-July more variation in seedling size became apparent, and the sample size was increased to 20. When the seedlings were lifted, 25 seedlings from each plot were sampled. For each measurement date, the ovendry weight of the entire shoot or root sample was determined, and the mean shoot and root dry weights per plot were calculated. During this sampling, the goal was to obtain, undamaged, the roots within the zone that would be lifted under operational conditions. Thus, no attempt was made to lift all the roots for each sampled seedling.

Differences in mean plot seedbed density were compared using analysis of variance. Treatment effects on mean shoot and root dry weights were analyzed by regression with the method of N application as an indicator variable. The regression models included rate of total N applied, method of application, and the rate by method interaction as independent variables. A significance level of $p = 0.05$ was used to eliminate independent variables from regression models and, if additional analyses were contemplated, to decide whether such analyses were warranted. For allometric regressions, the plot mean shoot and root dry weights were transformed to their natural logarithms. Values from all nine sampling dates were used in the allometric regressions.

Results And Discussion

Plot mean seedbed density was uniform across the study, averaging 257 seedlings per square meter with a coefficient of variation (CV) of 9.23 percent. Differences in mean plot density were not statistically significant ($p = 0.9$).

Treatment Effects on Seedling Dry Weight at Lifting

The method of applying N had no effect on the dry weight of either the shoots or the roots at the time of lifting (Fig. 1). For shoots, neither the interaction between rate of total N applied and method ($p = 0.9$) nor method alone ($p = 0.8$) affected the final dry weight. However, shoot dry weight did increase linearly with rate of N application ($p = 0.0001$):

$$ODW_{shoot} = 4521 + 11.6871 \text{ (rate of N)} \qquad [2]$$

The amount of N applied accounted for 38.4 percent of the variation in mean shoot dry weight at time of lifting. As with the shoots, neither the N rate by method interaction ($p = 0.9$) nor the method ($p = 0.9$) affected the final dry weight of the roots. The rate of N applied did influence root dry weight at lifting ($p = 0.0007$), and that relationship was also linear:

$$ODW_{root} = 820 + 1.5146 \text{ (rate of N)} \quad [3]$$

For mean root dry weight, total N explained 26.4 percent of the variation.

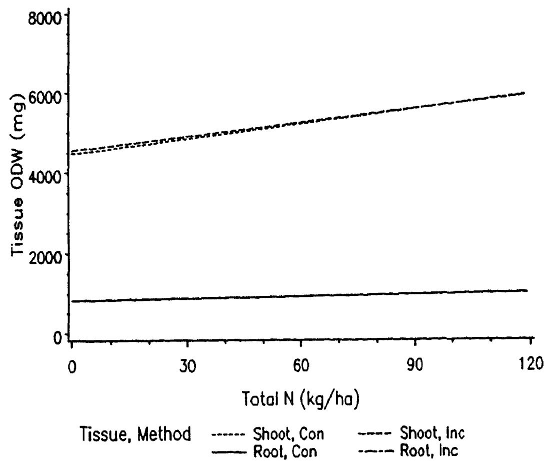


Figure 1. Effect of total amount of N applied and whether it was applied at a constant (Con) rate or at an increasing (Inc) rate on shoot and root ovendry weights of loblolly pine seedlings at lifting.

Although both shoot and root dry weight at lifting increased as more N was applied, the effect was not pronounced (Fig. 1). For each additional 30 kg N/ha applied, mean shoot dry weight increased 351 ± 72 mg, a 6.2 to 9.4 percent increase. Consequently, the shoots of seedlings that received 120 kg N/ha averaged 31 percent heavier at lifting than the seedlings that got no additional N. Mean root dry weight at lifting increased 45 ± 12 mg (or 4.0-7.0 percent) with each additional 30 kg N/ha applied. Thus, the roots of the most-fertilized seedlings averaged 23 percent heavier than those of seedlings with no additional N. Switzer and Nelson (1963) found a similar increase when they compared loblolly pine seedlings growing at a mean density of 322/m² and fertilized at either 84 or 168 kg N/ha.

The seedlings that received no additional N in this study were a somewhat paler green than the fertilized seedlings, but they showed no other symptoms of N deficiency, such as short, stiff needles (May 1985). Therefore, there was probably enough N in the soil at the beginning of the growing season for seedling growth and development. During seedbed preparation, about 11 kg N/ha was applied to the nursery soil (Gramling 1989). Moreover, longleaf pine (P. palustris Mill.) was grown in the nursery beds the previous year, and at Ashe Nursery longleaf pine typically gets more N fertilizer than loblolly pine. The year before this study, the area was fertilized with 336 kg/ha NH_4NO_3, 112 kg/ha diammonium phosphate (18 percent N), and 56 kg/ha of slow-release N fertilizer (38 percent N) (Gramling 1988), a total of about 155 kg N/ha. Carryover N from the longleaf pine crop, plus the preplant application before the study, must have provided enough N to meet at least the minimum requirements of the seedlings in the unfertilized plots.

Treatment Effects on Seedling Growth in The Nursery

When compared throughout the growing season in the nursery, neither the N rate by method interaction nor method alone affected the shoot dry weight (Table 1). In early June, both the rate by method interaction and method influenced root dry weight, but these factors had no further effect throughout the rest of the growing season.

'able 1. Significance levels for the effects of rate and method of N
ipplication on shoot and root dry weight.

;ample date	Shoot dry weight			Root dry weight		
	Rate	Method	Rate x meth	Rate	Method	Rate x meth
	------------- Probability of a larger F value --------------					
'un 6	0.823	0.708	0.420	0.731	0.031	0.010
'un 20	0.453	0.454	0.357	0.443	0.411	0.333
'ul 6	0.339	0.251	0.973	0.925	0.884	0.365
'ul 19	0.193	0.645	0.373	0.662	0.924	0.931
ug 15	0.003	0.215	0.254	0.382	0.264	0.123
;ep 12	<0.001	0.268	0.590	0.051	0.433	0.734
)ct 11	0.102	0.690	0.296	0.799	0.164	0.107
lov 14	0.004	0.946	0.989	0.039	0.644	0.649
'an 9	0.001	0.824	0.868	0.012	0.882	0.878

There are several possible reasons why the increasing-rate method did : increase root dry weight more than the constant-rate method in this idy. The level of N in the soil at the start of the experiment may have .minated the positive effects measured in other studies comparing the two :hods (Timmer and Armstrong 1987; Brissette et al., 1989). Also, the N ; applied over a relatively short time, when the seedlings were between : ages of 5 and 13 weeks, and the seedlings then grew for an additional 7 iths before lifting. In the container study by Timmer and Armstrong 987), fertilization was between 4 and 16 weeks after germination, and :n the seedlings were harvested.

Beginning in August for shoots and in September for roots, dry weights l increase with greater total N applied (Table 1). Because the dry ght of both shoots and roots increased linearly with the N applied, the 'ect of N on growth in the nursery can be demonstrated by comparing the) extreme treatments. In terms of mean shoot dry weight, the two treat- its began separating in mid-July (Fig. 2a), but root dry weights were iilar until mid-September (Fig. 2b). Generally, the fertilized seedlings itinued to grow faster throughout the rest of the growing season (Fig. b). Comparing Figure 2a with Figure 2b also shows that in both treat- its the rate of root growth was greatest after the rate of shoot growth ;an to decline (about mid-September). Between mid- September and early iuary, mean shoot dry weight increased 59 percent, and mean root dry ght increased 172 percent.

For unfertilized loblolly pine seedlings growing in central Louisiana,)erman (1940) reported that shoot dry weight increased 22 percent between 'ly October and January, while root dry weight increased 116 percent dur- ; the same period. At a nursery in Virginia using modern cultural prac- :es, shoot dry weight of loblolly pine seedlings increased 45 percent be- :en October and March, while root dry weight increased 189 percent irner and Dierauf 1976).

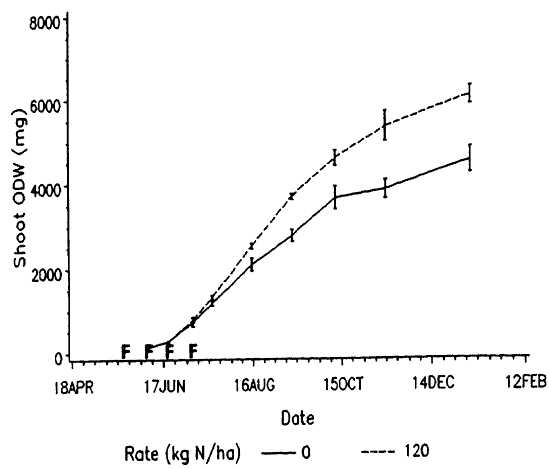


Figure 2a. Effect of the rate of total N applied on shoot dry weight on several measurement dates. Fertilization dates indicated by F. Vertical bars are ± 1 standard error.

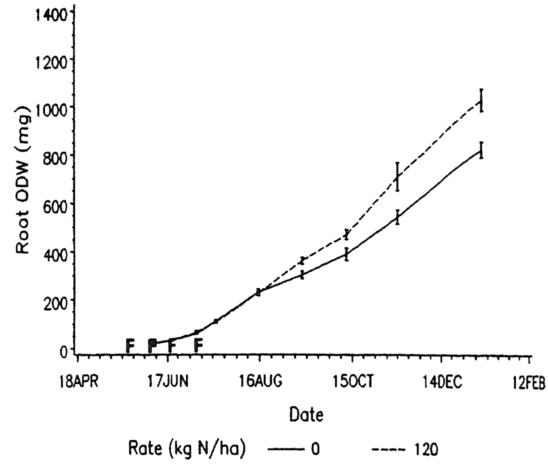


Figure 2b. Effect of the rate of total N applied on root dry weight on several measurement dates. Fertilization dates indicated by F. Vertical bars are ± 1 standard error.

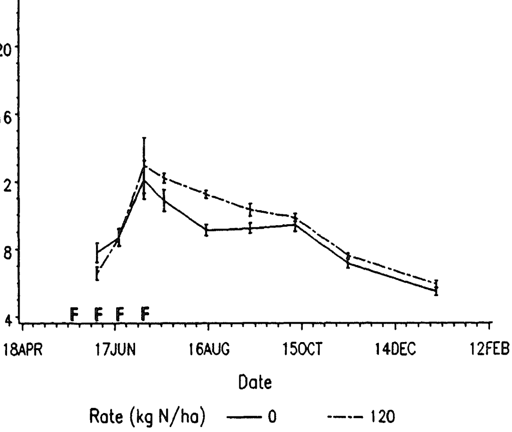
Although in this study the rate of root growth increased while that of shoot growth decreased starting in September, the shoot-to-root ratio declined steadily after peaking in early July (Fig. 3). In the study by Huberman (1940), the shoot-to-root ratio peaked in early September. Figure 3 also shows that the fertilized seedlings had a consistently higher mean shoot-to-root ratio throughout most of the growing season than the unfertilized seedlings. Similar results have been reported for loblolly and Virginia pines (P. virginiana Mill.) (Fowells and Krauss 1959), and for slash pine (P. elliottii Engelm.) (McGee 1963). When relative growth rates between May 24 and January 9 were compared by allometry, the rate of N applied had no effect on the shoots but did affect the roots somewhat (Fig. 4). For partitioning to shoot dry weight, the logarithm of the total seedling dry weight was highly significant ($p = 0.0001$), but rate had little impact ($p = 0.12$):

$$\ln ODW_{shoot} = -0.1090 + 0.9993\ (\ln ODW_{total}) + 0.00005\ (\text{rate of N}) \qquad [4]$$

This model explains 99.95 percent of the variation in the logarithm of shoot dry weight. Like the shoots, partitioning to the roots was strongly related to the logarithm of the total seedling dry weight ($p = 0.0001$), but it was also slightly related to the rate of N applied ($p = 0.07$):

$$\ln ODW_{root} = -2.2953 + 1.0059\ (\ln ODW_{total}) - 0.00054\ (\text{rate of N}) \qquad [5]$$

This model explains 96.5 percent of the variation in the logarithm of root dry weight. Although only marginally significant, the relationship between root dry weight and the rate of N applied was negative. This result agrees with the reported trend of relatively less total dry matter partitioned to



gure 3. Effect of the rate of tal N applied on the shoot-to- ot ratio on several measurement tes. Fertilization dates indi- ted by F. Vertical bars are ± standard error.

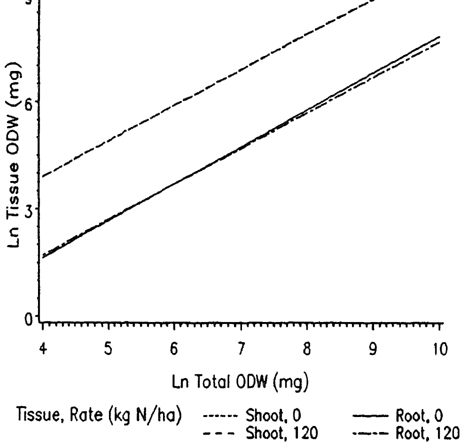


Figure 4. Allometric relationships throughout the growing season for shoot and root dry weight to total seedling dry weight when the seedlings received either 0 or 120 kg N/ha.

e roots of southern pine nursery stock as the rate of N increases (Fow- ls and Krauss 1959, McGee 1963, Switzer and Nelson 1963).

The regression coefficient for the relationship between the logarithms shoot dry weight and total seedling dry weight had a standard error (SE) ± 0.0012. The SE for the regression coefficient for the similar rela- onship for root dry weight was ± 0.0102. Therefore, the two regression efficients were essentially equal (i.e., they had parallel slopes). Con- quently, the mean relative growth rates--in percentage of dry weight owth per day--of the shoots and roots were similar. Although the rela- ve growth rates of the shoots and roots were the same, the shoots were avier throughout the study, so their absolute growth rate was greater an that of the roots. The slightly negative effect of rate of N on root lative growth rate in this study suggests that with more N applied, dry ight partitioning to the roots was reduced throughout the growing season.

It is possible that the fertilized seedlings produced more of their ot dry matter outside the lifting zone than the unfertilized seedlings. though the sampling method did not retain any roots outside the lifting ne, such roots would not be lifted under operational conditions either. though an extensive root system would be beneficial in the nursery, only e root system within the lifting zone affects field performance.

The results of this phase of the study do not yield any clear recommen- tions for nursery fertilization with N. A sample of seedlings from each ot was outplanted on a reforestation site in central Louisiana. Survival d growth data, in addition to these nursery results, will provide a basis r recommending fertilization of loblolly pine seedlings at Ashe Nursery.

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EFFECTS OF ORGANIC GROWTH-ENHANCEMENT COMPOUNDS ON LOBLOLLY PINE NURSERY SEEDLING GROWTH AND OUTPLANTING PERFORMANCE [1]

Ansel E. Miller, Thomas F. Ruckelshaus, and Lawrence E. Nix [2]

Abstract. Four organic growth-enhancement compounds [Roots™, Algrow™, Humus™ 12 percent liquid, and Humus Wettable Powder (WP 80™)] were tested for their effects on growth of loblolly pine seedlings in the nursery. Manufacturer recommended amounts were applied in an aqueous spray to seedlings in nursery beds each month from June through October. No significant differences in height, diameter or dry weight among treated and untreated seedlings were found during growth in the nursery. At lifting in January, height and diameter were either the same or less than that of untreated seedlings. There were no differences in first year field survival, which averaged 84 percent. Total height and diameter at the end of a year's field growth also differed little with treatment. In a second study trial, the same treatments were applied at two nurseries having different soil textures. Seedlings grown in sandy loam nursery soil had significantly greater size and dry weight than those grown in clay loam nursery soil. Within each nursery, there were no differences among treatments during growth and at winter lifting. First year survival of outplanted seedlings averaged 96 percent with no differences in growth and survival with nursery and treatment. Overall, the results suggest that these commercial organic growth-enhancement compounds applied at manufacturer recommended rates and used concurrently with forest tree nursery management practices do not provide any apparent short-term growth and survival benefits for loblolly pine.

Introduction

Management guidelines are well established for forest tree nurseries producing southern pine seedlings (Lantz, 1985). Horticultural nurseries, by contrast, usually grow more species, have smaller bed eas, and often produce seedli growing in pots. An important c production factor in each type nursery is the maintenance of s fertility and seedling nutrition

Nutritional needs are reac met by application of inorganic f tilizers. Often, substan amounts of fertilizer may be usec the forest tree nursery (May 198 Also, several metric tons per he of organic matter may be appliec forest tree nursery beds as mul In addition to inorganic fertil ers, horticultural nurseries o

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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e readily available commercial organic growth-enhancement compounds. ese cómpounds contain organic materials that can improve seedling growth aig 1972, Schnitzer and Khan 1972).

The use of commercially available organic fertilizers in large forest ee nurseries has not been explored. This study examines growth responses loblolly pine (Pinus taeda L.) seedlings in forest tree nursery beds eated with four different commercial organic growth-enhancement comnds. The objectives are to compare: (1) growth of organically treated h untreated (control) seedlings in the nursery; and (2) the effects of nursery soil textures (sandy soil and clay-loam soil) on seedling resse with organic compound applications. A third objective is to deterie the first year survival and growth of outplanted organically treated untreated (control) seedlings.

Materials And Methods

Organic growth compounds were applied during two separate years to loblly pine crops in a forest tree nursery. An operational study trial ite 1984) was conducted at the South Carolina State Forestry Commission edmont nursery near Salem, South Carolina, the first year. The second r, identical experiments were established at two State Forestry Commison nurseries (Piedmont and Taylor) to compare soil influences on treatt responses. The Taylor nursery is located in the sandhills region of state and has sandy soil, which differs from the heavier clay soil at Piedmont nursery.

st Study Trial

An area in the Piedmont nursery having six 100-m-long nursery beds was ected for the study. All beds were 1.2-m wide and adjacent to one aner. A 70-m-long bed length (plot) was established in each of the six s. Each plot was marked with stakes. Three plots were assigned to reve treatment with the organic compound Roots-160 while the other three ts served as untreated controls (Table 1). At the other end of the nury beds, four 6-m-long plots were established separately in adjacent beds test three other organic compounds (Table 1). These 6-m plots were ked with stakes and randomly assigned to be treated with Algrow, Humus 80, Humus 12 percent L, or to serve as an untreated control.

All treatment compounds were mixed with water and applied as an aqueous ay to drench the seedlings. Treatment applications were made during the dle of each month from June through October using manufacturer recomded concentrations (Table 1). Monthly treatments were applied on the 6-plots using a backpack Solo sprayer, while the larger 70-m-long plot atments were applied using a tractor-operated sprayer at the nursery. treated plots also received routine cultural treatments normally used oughout the nursery during crop growth.

During each monthly treatment application, a subsample of 12 seedlings removed from each treatment plot and brought to the laboratory for

Table 1. Organic compounds and concentrations applied each month o loblolly pine nursery seedlings.

Treatment compound	Concentration
Humus WP 80	14.6 g/10 m^2 (13.0 lb/ac)
Humus 12 percent L	9.4 ml/10 m^2 (1.0 gal/ac)
Algrow	5.0 g/10 m^2 (4.5 lb/ac)
Roots 160	40.7 ml/10 m^2 (4.4 gal/ac)
Control	---------

measurement. Seedling height, root collar diameter, and root, shoot, total dry weight were measured to follow the progress of seasonal gro through November. When the seedlings were lifted for field-planting in J uary, another sample of 30 seedlings was taken from each plot to test nursery treatment differences.

About 1000 seedlings from each treatment were lifted in January field outplanting tests. After lifting, the seedlings were packaged Kraft paper bags labeled by plot and treatment. All bags were transpor to a cooler for storage (2°C) the day after lifting. All seedlings w outplanted within a 2-week period.

The planting site was a typical Piedmont upland shortleaf pine st that had been recently clearcut and the slash burned. A randomized c plete block design having nine blocks was used for the outplanting. five nursery seedling treatments were randomly assigned row locations wi in each block. Seedlings in each treatment were hand-planted with a dib 0.3-m apart in a row, with 0.6 m between each of the five rows withi block. Height and diameter of each seedling was recorded 2 weeks af planting. Survival and final height and diameter were recorded in Decemb after completion of the first season of growth.

Second Study Trial

Minimal seedling growth responses in the nursery during first tr tests prompted a new experimental design for the second trial. An ditional nursery with sandy soil was included in the study to enhance p colation of organic amendments into the soil for root adsorption. Con quently, the South Carolina State Forestry Commission's Taylor nurse located near Edgefield, SC, in the sandhills region of the state, was cluded in the study in addition to the Piedmont nursery. Number of b and plots used at each nursery were increased to better quantify variat between and within nurseries and among treatments.

The same organic amendments and concentrations used in the first tr were applied again at both the Piedmont nursery and the Taylor nursery (ble 1). Study designs and methods were alike at both nurseries. Ei widely distributed beds within each nursery were selected for the stu

ithin each bed, 30-m bed lengths were marked with stakes and designated as locks. Each block was divided further into five 6-m-long plots. Plots ithin each block were randomly assigned to receive one of the four organic rowth-enhancement compounds, or to be an untreated control. Each compound as applied at manufacturer recommended concentration as an aqueous spray, renching the seedlings. Treatments were applied mid-month from June hrough November using a backpack Solo sprayer. All treated plots at each ursery received routine cultural treatments normally used for the entire ursery during crop growth. Cultural methods and timing of activities were imilar at both nurseries.

During nursery growth, seven seedlings were sampled from each treated lot on mid-monthly treatment dates and brought to the laboratory for meas-rement. Root collar diameter, shoot height, and shoot, root, and total ry weight were measured to monitor the progress of growth. In January, 2 onths after the final application, a sample of 30 seedlings from each nur-ery-block-treatment combination was obtained to determine seedling quality ifferences.

Seedlings from each plot were lifted and packaged in the routine manner uring January by personnel at each nursery. The seedlings were placed in raft paper bags labeled by nursery, block, and treatment. After lifting, ll bags were transported to a cooler (2°C) for storage. All seedlings were ield-planted within one week after lifting.

Seedlings from both nurseries were outplanted on the Clemson Experimen-al Forest. The planting site was a recent pine sawtimber clearcut that had een burned several months earlier. Seedlings from each nursery were hand-lanted with a dibble in separate, adjacent areas. A randomized complete lock design with eight blocks was established in each area, with each lock having a row of 35 seedlings. Each row contained five groups of even seedlings, with each group being one of the five nursery treatments. ursery treatment groups were randomly assigned within a row. Spacing of lanted seedlings was the same as that used in the first trial outplanting. wo weeks after planting, seedling height and root collar diameter were re-orded. Survival, height, and diameter were measured again in October, at he end of the first year's field growth.

Soil water infiltration rate in each nursery was determined using a urface ponding method described by Slatyer (1967). Nursery soil texture as measured using the method of Day (1956).

Results And Discussion

irst Study Trial

Monthly seedling samples showed no diameter or dry weight growth dif-erences among the organic compound treatments during growth in the nur-ery. Seedling height proved unsuitable for evaluating growth after Sep-ember because of top-pruning. When treated seedlings were lifted for utplanting in January, height, diameter, and dry weight measurements ap-eared different for Algrow and the two Humus treatments (Table 2). How-ver, use of 6-m plots in separate beds did not permit separation of nur-ery bed (location) effects from treatment effects. Use of three beds

(replications) for the Roots 160 along with an untreated control treat
showed there were no differences in seedling morphology for this comp
(Table 2).

Table 2. Height, diameter, and total dry weight of treated Piedmo nursery loblolly pine seedlings when lifted in March for field planti (first growth trial).

Treatment	Height	Diameter	Total dry weight
	(cm)	(mm)	(gm)
Humus WP 80	32.7 a[1]	4.4 a	2.89 a
Humus 12 percent L	35.1 a	5.5 ab	5.81 ab
Algrow	28.2 b	4.5 a	3.56 a
Roots 160	34.1 a	6.3 b	7.18 b
Control	36.0 a	6.5 b	8.65 b

[1] Means followed by the same letter within a column are not signif cantly different at the 0.05 level of probability.

There were no clear benefits from seedling treatments after a ye growth in the field (Table 3). At the end of the first growing sea outplanted seedling total height averaged 45.1 cm for all treatments, a difference of 4.0 cm between the shortest and tallest treatment gr There was no improved diameter growth. Clearly, treatment effects were large following a year's growth in the field.

Second Study Trial

A comparison of nursery soils at the Piedmont and Taylor nurse shows the Piedmont nursery had greater amounts of silt and clay (Table Also, the water infiltration rate was slower and the organic matter con was higher than at the Taylor nursery. Clearly, absorption of aqueous ganic compounds by way of percolation into the soil was favored at the lor nursery because of its more porous soil.

Monthly samples taken from each treatment during the progress of s ling growth at both nurseries showed no growth differences among org compound treatments. At lifting in January, seedling measurements a showed no morphological differences with treatment, but there were sign cant differences in total seedling dry weight between nurseries (Table Clearly, application of these organic compounds resulted in no consis growth differences at either nursery.

Field outplanting tests similarly showed no differences among tr ments following completion of the first season of growth (Table 6). vival was 90 percent or greater for seedlings from both nurseries and f

ing (first growth trial).

Treatment	Total height	Diameter	Survival
	(cm)	(mm)	(percent)
Humus WP 80	44.9 a[1]	8.3 a	85.6 a
Humus 12 percent L	42.8 a	7.1 b	83.8 a
Algrow	45.2 a	8.5 a	79.4 a
Roots 160	46.0 a	8.7 a	85.5 a
Control	46.8 a	8.7 a	84.0 a

[1] Means followed by the same letter within a column are not significantly different at the 0.05 level of probability.

Table 4. Texture, infiltration rate, organic matter and pH of soils at the Piedmont and Taylor nurseries.

Nursery	Texture sand	Texture silt	Texture clay	Water infiltration rate	Organic matter	pH
	----- percent ------			---- cm/hr ----	percent	
Piedmont	65 a[1]	23 a	12 a	9 a	4.3 a	5.8 a
Taylor	90 b	8 b	2 b	70 b	0.9 b	5.5 a

[1] Means followed by the same letter within a column are not significantly different at the 0.05 level of probability.

l treatments. Height and diameter growth in the field was significantly eater for seedlings from the Piedmont nursery, but there were no treatnt differences. The difference in treated seedling height was 3.4 cm for th nurseries, while the difference in mean diameter was 1.3 mm and 1.0 mm r seedlings of Piedmont and Taylor origin, respectively.

Summary

Overall, results of both trials show that the commercial organic owth-enhancement compounds used in this study caused little change in blolly pine seedling growth. Also, nursery-treated seedlings from both

Table 5. Height, diameter, and total dry weight of treated Piedm and Taylor nursery loblolly pine seedlings when lifted for field plan ing in January (second growth trial).

Nursery	Treatment	Height	Diameter	Total dr weight
		-- cm --	-- mm ---	--- gm -
Piedmont	Humus WP 80	22.7	4.8	3.7
	Humus 12percent L	22.2	4.6	3.4
	Algrow	22.0	4.6	3.5
	Roots 160	23.0	4.8	3.5
	Control	24.1	4.6	3.5
	Average	22.8 a[1]	4.7 a	3.5 a
Taylor	Humus WP 80	24.1	5.0	4.2
	Humus 12 percent L	24.5	5.0	4.2
	Algrow	24.5	5.1	4.3
	Roots 160	24.4	4.9	3.9
	Control	22.8	4.7	3.7
	Average	24.1 a	4.9 a	4.1 b

[1] Nursery means followed by the same letter within a column are significantly different at the 0.05 level of probability. Treatm means within nurseries did not differ.

trials did not show any added benefit after completion of a year's g in the field. Increased concentrations of the compounds may be nece before responses can be observed. However, the amounts of inorgani trients applied to forest tree nursery beds may mask any beneficial ef caused by these organic growth-enhancement compounds.

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ings treated with organic compounds during growth in the nursery (sec-
nd growth trial).

ursery	Treatment	Total height	Diameter	Survival
		--- cm ---	-- mm --	percent
iedmont	Humus WP 80	39.4 a[1]	8.8 a	98 a
	Humus 12 percent L	41.0 a	9.5 a	90 a
	Algrow	41.1 a	10.1 a	100 a
	Roots 160	42.6 a	9.8 a	94 a
	Control	41.6 a	9.5 a	96 a
aylor	Humus WP 80	36.4 a	6.9 a	90 a
	Humus 12 percent L	39.0 a	7.5 a	95 a
	Algrow	40.0 a	7.9 a	95 a
	Roots 160	40.0 a	7.8 a	100 a
	Control	38.0 a	7.3 a	98 a

Means followed by the same letter within a column for each nursery are not significantly different at the 0.05 level of probability. Treatment means between nurseries did not differ.

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Gary L. Buchschacher, Patricia T. Tomlinson, Paul S. Johnson, and J.G. Isebrands [2]

Abstract. Current nursery practices for rearing northern red oak (Quercus rubra L.) seedlings result in wide variation in quality. This variation has led to reluctance in using planted oak seedlings for regeneration. The objective of this study was to determine the effects of seed source and nursery cultural practices on seedling quality at the Wilson State Nursery in Boscobel, Wisconsin. Observations using five seed sources and four cultural practices suggest that superior tree seed sources and appropriate cultural practices promote early emergence and greater growth, resulting in superior quality seedlings.

Introduction

Current nursery practices for rearing northern red oak (Quercus rubra L.) seedlings result in wide variation in seedling quality. Variability in stem caliper, stem height and seedling vigor have resulted in a reluctance to use planted oak for regeneration. Kormanik and Muse (1986) and Johnson (1989) have shown that the number of persistent lateral roots, stem caliper, stem height, and seedling vigor are key factors for successful establishment. The production of high quality seedlings has been addressed in several other studies. For example, persistent lateral root production was enhanced by undercutting nursery stock (Johnson 1988), whi the importance of pH, fertilizati and undercutting was discussed Crow and Isebrands (1986).

The objective of this study w to test the effects of seed sourc undercutting, soil amendment wi peat, and emergence time on nurse seedling quality.

Materials And Methods

This study was conducted at t Wilson State Nursery, Boscobel, Wi consin, in cooperation with t Wisconsin Department of Natural R sources (DNR). Half-sib acorns we collected in fall 1989 from four i dividual trees (seed sources 1 to in northern Wisconsin. These tre represented superior phenotypes a were growing on sites of at lea site index 65 for northern red o (Lundgren and Dolid 1970). For co parison, acorns from the 1989 D public collection (the fifth se source) were also obtained.

After collection, seeds we immersed in water and floati acorns were discarded. T

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Biological Lab Technician, Research Plant Physiologist, North Central Forest Exp. Sta., Rhinelander, WI; Research Forester, NCFES, Columbia, MO.; and Tree Physiologist, NCFES, Rhinelander, WI.

mplete and proper hydration (Teclaw and Isebrands 1986). They were then rface dried and stored at 1 to 3°C until planting. The public collection ed was also floated and hydrated prior to planting.

Four replicates were planted in a 153-m bed row using a split-split-ot experimental design to test for differences among undercutting treat-nts, peat amendment, and seed sources 1 to 4. A split-plot experimental sign was used to test for differences in emergence and survival between ed sources 1 to 4 and the public collection seed.

Prior to planting, 0.12 m^3 of sphagnum peat moss (pH ca. 4.5) was till- into each 1.2 x 2.4-m peat amendment plot to a depth of 20 cm. Acorns re sown on October 24-25, 1989, at a spacing of 10 x 12 cm and a depth of cm in the 1.2-m-wide nursery bed row; a template was used to assure con-stent spacing and planting depth. Two weeks following planting, the row s covered with about 5 cm of ground corn cob mulch. This mulch was re-ved by hand on April 9, 1990.

To provide information on the effects of emergence time on seedling ality, an additional study consisting of 10 seed sources was planted as scribed above. Within those 10 seed sources, two were the same as those ed in the main study, and the cultural practices were comparable to the n-undercut, peat-amended main study plots.

Emergence counts were made on May 10 and at approximately 2-week inter-ls until the count remained constant for two consecutive periods. Early edlings were those emerging between May 10 and May 25, while late seed-ngs were considered to be all seedlings emerging after May 25th. Survi-l was estimated from a final count made on August 21, 1990.

Seedlings were fertilized (110 kg/ha 33-0-0 plus 55 kg/ha of 0-0-50) ery 2 weeks from June through August. Plants were irrigated as needed to intain adequate soil moisture.

The Quercus morphological index (QMI) was used to assess the morpholog-al stage of seedling development (Hanson et al., 1986). On July 10, 90, appropriate treatment plots for seed sources 1 and 4 were undercut. that time, 78 percent of the seedlings were in the 2 Lag stage of devel-ment (i.e., second flush leaves fully expanded), 16 percent were slightly st 2 Lag, and the remaining 6 percent were younger than 2 Lag. Seedlings re undercut with a Fobro™ lifting machine with the blade set as close to rizontal as possible, at a depth of 15 cm. The agitation bar of the Fob- was not used. Plants were irrigated for 1 hour after undercutting.

On September 21, 1990, above-ground seedling characteristics of 10 edlings in plots representing each seed source and treatment were re-rded and subsamples from these plots were harvested to obtain below-ound characteristics. Measurements of seedling quality were stem caliper the soil line (ca. 2 cm above the root collar), stem height, number of rsistent lateral roots (defined as first-order lateral roots > 1 mm

diameter; used to determine root grades), and number of flushes. Each s cessive root grade constitutes an increase of five persistent late roots; i.e., root grade 1 designates 0 to 5 laterals roots and root gr 4, 15 to 20 laterial roots. Only lateral roots on the first 15 cm of t root were counted because any deeper lateral roots and taproot would lost after undercutting or mechanical lifting. All data were expressed the mean ± standard error of the mean.

Results and Discussion

Over the 16-week observation period, seed sources 1 to 4 produced se lings with significantly greater early emergence rates and total emerge (wk 1 to 6), and higher survival rates (wk 16) than those from the pub collection; e.g., 88 percent emergence and survival for seed sources 1 t compared with 54 percent for the public collection (Fig. 1). In additi emergence rates differed among the seed sources, seed source 2 had the m rapid emergence rate (Fig. 1).

Although there was no difference in number of flushes, early emerg seedlings had greater stem caliper and height than did late emergent se lings (Fig. 2). Similarly, stem caliper and height differed among s sources 1 to 4 (Fig. 3 and 4); seedlings from seed source 4 had grea stem caliper and height compared with seedlings from the other s sources. No difference in the number of flushes was detected among s sources 1 to 4 (Fig. 3 and 4). Undercutting decreased stem caliper height in all seedlings but seedlings from seed source 4 were still tal than those from seed sources 1 and 3 (compare Fig. 3 with Fig. 4).

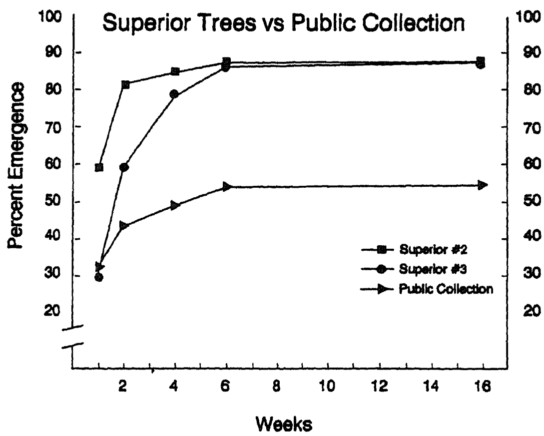


Figure 1. Comparison of emergence (wk 1 to 6) and survival (wk 16) among seed sources 2, 3, and the public collection seed. Seedling response of seed sources 1 and 4 were intermediate to sources 2 and 3 and are not presented for clarity.

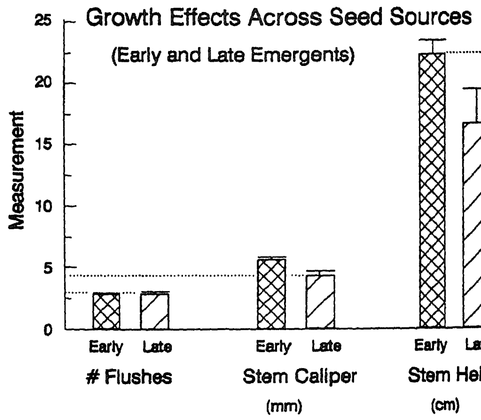
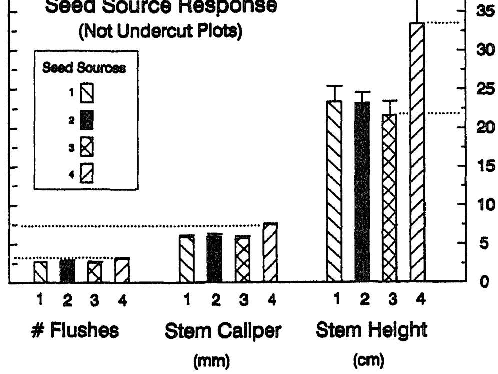


Figure 2. Effect of emergence t on above-ground seedling charact istics averaged over 10 seed so ces. Early seedlings emerged tween May 10 and May 25, while l seedlings emerged after May 25.



ure 3 Effect of seed source, wn in non-undercut plots, on ve-ground seedling character- ics.

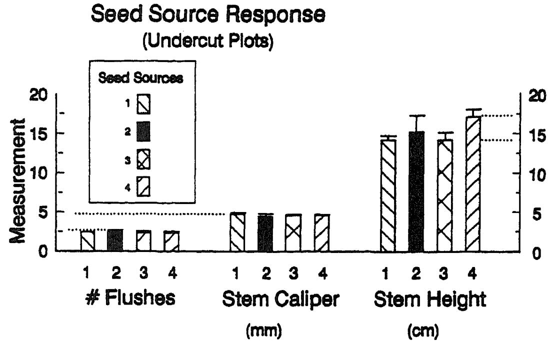
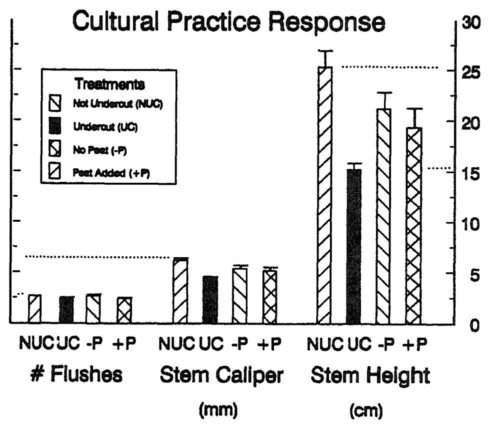


Figure 4. Effect of seed source, grown in undercut plots, on above-ground seedling characteristics.

The greatest treatment effects resulted from undercutting. Undercutting reased both stem caliper and height (Fig. 5) and increased the number of sistent lateral roots (Fig. 6). The number of lateral roots increased m 10±1 for seedlings not undercut to 18±1 for undercut seedlings: a sig- icant increase. Soil amendment with peat had no effect on growth (Fig. but increased the number of lateral roots slightly (Fig. 6). Peat ndment decreased soil pH from 5.8±0.2 to 5.0±0.1 (measured at planting, l 1989). Thus, the increase in number of lateral roots was presumably to improved soil texture as well as changes in pH.



ure 5. Cultural practice ef- ts on above-ground response of dlings from seed sources 1 to 4.

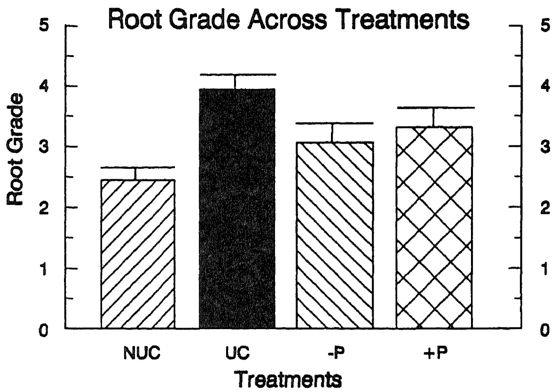


Figure 6. Cultural practice effects on root grade of seedlings from seed sources 1 to 4. (Root grades are defined by the number of persistant laterals, e.g., root grade 1 is 0–5 laterals and root grade 5 is >20 laterals. Treatments as in Figure 5.)

The results of this preliminary study show that early emergent seedlings have greater stem caliper and height than late emergent seedlin Seedlings from individual, superior tree seed displayed earlier and grea percent emergence. In addition, undercutting and peat amendment increa the number of persistent lateral roots. Given these results, oak seedl quality would be improved by the use of seed collected from superior tr or stands (registered for collection) rather than seed purchased from restricted public collections, and by undercutting and peat amendment nursery beds. Together these practices should decrease seedling variabi and increase seedling quality and outplanting success.

Acknowledgment

Authors wish to acknowledge the support and cooperation of the Wisc sin Department of Natural Resources for this project.

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RED OAK SEEDLINGS IN HIGH AND LOW MOISTURE ENVIRONMENTS [1]

Charles J. Barden and Todd W. Bowersox [2]

Abstract. This study evaluated the influence of presowing radicle clipping on subsequent growth in high and low soil moisture environments of northern red oak seedlings from five families. The radicle clipping treatment slightly improved 1st-year outplanting shoot growth over control seedling levels. End-of-season shoot diameter, height, and volume were all significantly increased by the treatment. There were significant interactions between the families and soil moisture levels. Root/shoot ratios were not significantly increased by the low moisture environment. The results indicate that radicle clipping may be useful in improving northern red oak (<u>Quercus</u> <u>rubra</u> L.) seedling field performance.

Introduction

Outplanting of seedlings is of- done in forestry research to de- mine the practical utility of ious cultural treatments under ld conditions. If a greenhouse wth response is not repeated in field, then the controlled envi- ment results may be of little ctical importance. Root growth acity (RGC) is the measure of dling ability to rapidly grow new ts when planted into a controlled ironment. RGC has been correla- with outplanting shoot growth survival in several tree species tchie and Dunlap 1980), including thern red oak (<u>Quercus</u> <u>rubra</u> L.), (Webb and von Althen 1980, Larson 1988). Furthermore, Barden and Bowersox (1989) have shown northern red oak RGC to be improved by a combination treatment of radicle clipping with lateral root pruning.

Burdett (1987) noted that reports relating laboratory RGC to field root growth are absent from the literature. A key question is: "Do high RGC levels in short-term greenhouse tests translate to superior root growth in the field?" The answer to this question will provide insights as to how and why the RGC test indicates planting stock quality. As an intermediate step, this study allowed intensive sampling of northern red oak seedling shoot and root growth after one growing season under high and low soil moisture "field" conditions. The objective of this study was to evaluate the influence of presowing radicle clipping on the subsequent growth of northern red oak seedlings from five families grown in high and low moisture environments.

Paper presented at Sixth Biennial thern Silvicultural Research Con- ence, Memphis, TN, Oct. 30-Nov. 1990.

Area Extension Forestry Special- , Oklahoma State Univ. Extension ter, McAlester, OK; and Profes- , Penn State Univ., State Col- e, PA.

Materials And Methods

Acorns were collected from four planted northern red oak trees growing adjacent to each other in Lebanon County, southeastern Pennsylvania. One family was collected from a planted tree on the Penn State University campus in State College, Pennsylvania. Seed sources of these planted trees are unknown. The seedlots used were thus from five open-pollinated families. All seedlots were gathered during September and October 1986. The acorns were held uncovered indoors for two weeks at room temperature, and overwintered in cold storage at 1°C in covered containers.

Acorns were removed from storage in May 1987, soaked in water for 24 hours, and kept moist at room temperature to promote sprouting. The length of the emerging radicle was reduced by one-half, as the distal portion was removed with a razor blade on one-half of the acorns. The radicles were approximately 1-4 cm-long when the clipping was performed. In June 1987, all acorns were planted into three replications within a nursery bed at Penn Nursery, operated by the Pennsylvania Bureau of Forestry. The seedlings were raised using operational nursery practices for irrigation, fertilization, weeding, and insect control. All seedlings were machine lifted from the nursery in April 1988 and held in cold storage at 2°C for 1 month.

The seedlings were planted into boxes filled with a Morrison sandy loam forest soil. Six plywood frames, 1.22 x 1.22 x 0.61 m (L x W x H) with 10-mm mesh screen bottoms, were lined with 3-4 cm of gravel. The boxes were filled with soil and three each were maintained at either a high or low soil moisture level. A preplanting application of 47.6 g of fertilizer (8-16-16) was incorporated into the upper soil layers of each box. This rate corresponds to 25.6 kg of nitrogen per hectare. In mid-July, 32.8 g of urea (46-0-0) were applied to each box, which corresponds to a 101.4 kg/ha rate of nitrogen. These heavy rates of fertilization were used due to the infertile nature of the Morrison soil.

Twelve seedlings from each treatment of the five families (n = 120) were planted at a density of 30 seedlings/m^2 in a randomized complete block design. The moisture treatments were maintained by differential irrigation rates, and by sheltering the boxes from natural precipitation. All irrigation events were timed to allow calculation of the amount of water actually applied (i.e., 10 min = 3 cm). Actual soil moisture levels were documented weekly at three depths by data from a 310A moisture temperature cell obtained from SOILTEST Inc., Evanston, Illinois.

All seedling root systems were pruned to a length of 20 cm before planting. Initial shoot height and groundline diameter were recorded for each seedling. At the end of the growing season the final shoot diameter, height, terminal dieback, and number of flushes were recorded for each surviving seedling. Shoot volume was calculated as an index (diameter^2 x height). The boxes were then dismantled and the soil washed from the root systems to allow sampling of root growth. Shoot and root system dry weights were obtained for each surviving seedling. The root system was divided into two components by removing all new roots originating at 20 cm from the groundline and weighing them separately. Thus, the root system

was divided into the original, planted roots, and the new roots originating after transplanting.

Analysis of variance (ANOVA) and covariance were used to ascertain significant treatment effects. Duncan's New Multiple Range Test was used to evaluate treatment means using the SAS (SAS 1987) statistical package.

Results

Radicle Clipping Effects

The mean shoot volume increment of the five families over both moisture regimes was increased significantly (68 percent) by the radicle clipping treatment (Table 1), although radicle clipping resulted in a nonsignificant increase in height increment. Neither the length of shoot dieback nor the number of shoot flushes were significantly affected by the radicle clipping treatment.

Table 1. Shoot growth responses to radicle clippping of northern red oak seedlings from five families planted into high and low soil moisture environments.

Morphological measure	Unit	Radicle not clipped (control)	Radicle clipped
Initial diameter	mm	4.7 b[1]	5.3 a
Diameter increment	mm	1.1 a	1.1 a
Final diameter	mm	5.8 b	6.5 a
Initial height	cm	20.5 b	24.2 a
Height increment	cm	8.2 a	10.9 a
Final height	cm	28.6 b	34.9 a
Volume increment	cm^3	6.3 b	10.7 a
Final volume	cm^3	11.3 b	18.4 a
Dieback	cm	7.4 a	6.1 a
Flushes	no.	1.7 a	1.9 a

[1] Means within a row followed by the same letter are not significantly different at the $P < 0.05$ level.

The final shoot diameter, height, and volume measures were all significantly greater for radicle clipped than for control seedlings (Table 1). Final shoot volume was the most responsive variable, exhibiting a greater than 60% increase due to radicle clipping. The greater response of the final shoot measures may be partially due to the significantly larger initial shoot size of the radicle clipped seedlings (Table 1), although analysis of covariance indicated a significant radicle clipping effect beyond initial height and diameter measures. Analysis of covariance indicated that initial shoot diameter was significantly related to diameter increment ($P < 0.01$), final diameter ($P < 0.0001$), final height ($P < 0.05$), and final volume ($P < 0.0001$). Initial shoot height was a significant covariate only of height increment ($P < 0.0005$).

The radicle clipping treatment significantly increased the dry weight of the shoot and the original roots over control seedling levels (Table 2). Shoot dry weight was more strongly affected, exhibiting a 30 percent increase. Total root system dry weight and new root dry weight were slightly, but not significantly greater for radicle clipped seedlings. Root/shoot ratio was not significantly affected by radicle clipping.

Table 2. Ovendry weight measures and maximum root depth in response to radicle clipping of northern red oak seedlings from five families transplanted into high and low soil moisture environments.

Response measure	Unit	Radicles not clipped (control)	Radicles clipped
Shoot weight	g	4.22 b[1]	5.52 a
Root system weight	g	20.16 a	23.58 a
Original root weight	g	13.91 b	16.79 a
New root weight	g	6.25 a	6.85 a
Root/shoot ratio	-	6.15 a	5.02 a

[1] Means within a row followed by the same letter are not significantly different at the $P < 0.05$ level (n varied from 67 to 69).

Family and Soil Moisture Effects

The differential moisture contents of the high and low soil moisture treatments are documented in Table 3. The treatments correspond to a well watered and a droughty environment. During the growing season (June-September), the high moisture boxes received 40.3 cm of combined precipitation and irrigation while the low moisture boxes received only 11.3 cm.

The families exhibited complex responses to the differential soil moisture levels. There were significant interactions between the families and the soil moisture levels for diameter increment ($P < 0.005$), height increment ($P < 0.05$), volume increment ($P < 0.05$), final diameter ($P < 0.005$), final height ($P < 0.05$), and final volume ($P < 0.01$). Due to these interactions, the means are presented in Table 4 by family and soil moisture level, and only general trends of the family and soil moisture main effects can be discussed.

Families 1, 4, and 5 responded to the high soil moisture environment by significantly increasing growth over that observed in the low soil moisture boxes (Table 4). Family 2 responded to the high moisture environment with only small, nonsignificant growth increases. However, Family 3 exhibited nonsignificantly reduced shoot diameter and volume increments when grown in the high soil moisture environment (Table 4). The significance of the interactions is primarily due to the unusual growth response of Family 3. Shoot growth means by soil moisture level are also presented in Table 4.

When averaged across families, diameter increment, height increment, and volume increment, were all three times greater for seedlings grown in the high moisture boxes compared with the low moisture boxes. The growth advantage of seedlings grown in the high moisture boxes was evident.

Table 3. Mean soil moisture contents (percent ovendry weight) averaged over the growing season at three soil depths for the low and high soil moisture boxes.

Moisture levels	Soil depth (cm) 15	30	45
Low	18.5 a[1] (6)[2]	18.2 b (5)	17.8 b (5)
High	19.7 a (6)	22.8 a (0)	23.0 a (0)

[1] Means within a column followed by the same letter are not significantly different at the $P < 0.05$ level ($n = 12$).

[2] The number in parentheses is the frequency of observed moisture contents below 15 percent.

Table 4. Shoot growth responses to high and low soil moisture conditions of five families of northern red oak seedlings across radicle clipping treatments.

Family and moisture level	Shoot growth responses: Diameter increment	Final diameter	Height increment	Final height	Volume increment	Final volume
	(mm)	(mm)	(cm)	(cm)	(cm^3)	(cm^3)
1 Low	0.04 b[1]	4.83 b	-2.43 b	21.57 b	-0.43 b	5.38 b
1 High	1.71 a	6.94 a	19.35 a	42.55 a	15.16 a	21.98 a
2 Low	0.39 a	6.02 a	3.60 a	31.40 a	2.58 a	11.92 a
2 High	1.09 a	6.47 a	7.25 a	32.50 a	6.29 a	14.29 a
3 Low	1.52 a	6.46 a	9.11 a	30.56 a	7.23 a	14.01 a
3 High	0.97 a	6.20 a	10.14 a	29.64 a	7.04 a	13.23 a
4 Low	0.42 b	5.04 b	5.33 a	25.11 b	4.14 b	8.81 b
4 High	2.54 a	7.24 a	18.85 a	40.45 a	18.72 a	23.84 a
5 Low	0.32 b	5.14 b	6.20 a	25.25 a	4.11 b	8.97 b
5 High	2.23 a	7.53 a	18.57 a	39.79 a	23.95 a	30.74 a
Mean low	0.55	5.53	4.69	27.08	3.69	10.04
Mean high	1.64	6.81	14.21	36.49	13.19	19.81

[1] Means followed by the same letter are not significantly different at the $P < 0.05$ level. Comparisons are made only within families (n varied from 7 to 12).

The family ovendry weight data was not as prone to interactions as the shoot height and diameter data. Shoot ovendry weight was significantly higher for seedlings subjected to the high soil moisture conditions (Table 5). No shoot ovendry weight interactions were significant. Total root system, and original root ovendry weights were not significantly affected by the soil moisture levels (Table 5). However, new root weight did exhibit a significant interaction ($P < 0.05$) between the families and moisture levels, similar to the shoot growth responses. Families 1 and 4 significantly increased their new root ovendry weight in response to the higher soil moisture environment, whereas Families 2 and 3 exhibited nonsignificant reductions in new root ovendry weight in that environment. Root/shoot ratio was not significantly affected by soil moisture level.

Table 5. Ovendry weight responses of northern red oak seedlings from five families to low and high soil moisture levels.

Response	Unit	Soil moisture	
		Low	High
Shoot	g	3.79 b[1]	5.92 a
Root system	g	20.92 a	22.95 a
Original roots	g	15.03 a	15.85 a
New roots	g	5.98	7.10
Root/shoot ratio	-	6.15 a	5.02 a

[1] Means within a row followed by the same letter are not significantly different at the $P < 0.05$ level. Due to the significant interaction between families and soil moisture on new root weight no means separation are reported for this variable.

Discussion

The radicle clipping treatment consistently improved shoot growth over control seedling levels, although the difference was only significant for volume increment. Final shoot diameter, height, and volume were all significantly increased by radicle clipping. Radicle clipping only resulted in nonsignificant increases in new root ovendry weight and total root ovendry weight.

The families displayed complex responses to the soil moisture levels, resulting in significant interactions for all shoot increments and final size measures. Family 3 was ranked first in diameter and volume increment when grown in the droughty boxes, but was ranked last and fourth, respectively, in the high moisture boxes. The other families all responded to higher moisture levels by increasing their growth by varying degrees. New

aying significant reductions due to droughty conditions, while Families 2 d 3 displayed slight growth increases in the drier environment. Thus, ese families may vary in their degree of adaptation to drought, as evinced by their differential growth response to the high and low soil moisre environments.

Overall, the pre-sowing radicle clipping treatment improved the end-ofason shoot growth in outplanted seedlings. Thus, radicle clipping may be eful in improving northern red oak seedling performance. Also, the rong family by moisture level interaction illustrates the need to carelly consider genotype effects whenever assessing cultural treatments.

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HERBICIDE AND BURN SITE PREPARATION IN THE GEORGIA PIEDMONT [1]

Dave L. Bramlett, Earle P. Jones, Jr., and Dale D. Wade [2]

Abstract. A 40-ac harvested loblolly pine (Pinus taeda L.) stand in the Lower Georgia Piedmont was divided into five randomized blocks, each containing four, 2-ac treatment plots. Treatments were: (1) herbicide followed by burning, (2) herbicide alone, (3) drum chopping, and (4) control. Herbicide application consisted of a Garlon 4™ and Tordon 101™ mixture applied with ground equipment in July 1987. Burning was done in September 1987. Chopping with an offset roller drum was completed in July 1987. Loblolly pine seedlings were planted in February 1988 and measured after one, two, and three growing seasons. After 3 years, mean height, diameter and volume index of the seedlings planted after herbicide application and burning were significantly larger than those on any other treatment area. Seedlings on plots treated only with herbicide were taller and had a higher volume index than seedlings on mechanically chopped plots and control plots. There was no significant difference in pine seedling survival among treatments. These results indicate that herbicide application followed by burning is an effective way for landowners to regenerate neglected cutover sites.

Introduction

Low-cost, effective procedures to regenerate loblolly pine (Pinus taeda L.) after harvest may be the key to reversing the decrease in the acreage of well-stocked pine stands in Georgia. Too often, nonindustrial private forest (NIPF) landowners cut mature stands of loblolly pine, realize a substantial income, but fail to make any effort to regenerate the harvested area to loblolly pine. If, fortuitously, some pine regeneration becomes established and successfully competes with the hardwood vegetation, a mixed pine-hardwood stand may develop. After two or three similar cutting cycles, however, the pine component is virtually eliminated and cull or low value hardwoods dominate the site.

Sites can be prepared mechanically, chemically, by burning, or through combinations of these methods. Intensive mechanical site preparation, such as rootraking, windrowing, and disking increases early growth of planted pines (Lantagne and Burger 1987; Edwards 1990). It reduces woody competition and creates exposed soil conditions like those of abandoned agricultural land. Mechanical site preparation, however, often costs more than NIPF

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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ndowners are willing to invest in pine regeneration (Straka et al., 1989) d can cause site deterioration (Mitchell 1988).

Herbicide applications for site preparation have gained wide acceptance the past decade (Merck 1989). The obvious advantage of chemical site eparation is minimal soil disturbance. A disadvantage is that even ough the vegetation is killed or severely affected by the herbicide, a rge amount of standing debris remains on the site making a difficult anting job. In addition, some plant species may resist the herbicide sed and survive to compete with planted pine.

Fire is the classic site preparation method for replanting harvested uthern pine sites. The use of prescribed fire throughout the rotation n eliminate or greatly reduce hardwood competition (Jones 1989). And oadcast burn after logging can dispose of much of the logging debris. e large amount of available fuel at that time can carry an intense enough re to kill the tops of fairly large residual hardwoods. One disadvantage burning after logging is that the logging operation disrupts fuel con- nuity so that a fire may not carry over the entire area.

Combinations of mechanical and fire treatments such as drum chopping d broadcast burning or felling and burning can be very effective. Herbi- de and fire combinations also have synergistic effects (Clawson 1989). e correct herbicide will kill or severely damage much of the hardwood and rbaceous vegetation, increasing the amount of fuel available to carry a re. Thus, the fire is more likely to burn through areas of understory getation that would not burn without prior herbicide treatment. Dead els created by applying herbicide also make ignition easier and permit rning on days when the fire hazard is relatively low.

The study described here was established to evaluate three postharvest te preparation alternatives that are commonly used by NIPF landowners in e Georgia Piedmont. The study was located on private land near the Ernst ender Demonstration Forest in Jones County, Georgia, so that tour groups uld compare these regeneration methods with preharvest site preparation ternatives as reported in these proceedings (Wade et al., 1991).

Methods

The study was installed on an area where the pine sawtimber and pulp- od had been harvested in 1985. By 1987, residual understory and over- ory hardwoods dominated the site, and hardwood sprouts, weeds, and vines re well established. In July 1987, five randomized blocks of 8-ac each re delineated and the following four treatments assigned: (1) herbicide plication followed by burning (brown and burn); (2) herbicide only; (3) um chopping; and (4) control. Each treatment plot was approximately 2 ac size. A 0.2-ac measurement plot was located in the center of each 2-ac eatment plot to measure development of seedlings to be planted after eatment applications. A concentric 0.02-ac plot was established to re- rd the growth of understory stems greater than 4.5 ft tall but less than .6 inches in diameter.

Herbicide was applied with a tractor-mounted sprayer on July 16-17, 1987. The equivalents of ½ gal of Garlon 4™ and 1½ gal of Tordon 101™ were applied per acre (products registered by Dow Chemical Company). A spreader/sticker (Cide-kick) was mixed with the water solution. Approximately 25 gal of solution were applied per acre by making seven single passes across the 2-ac treatment plot with a 40-ft distance between passes.

Burning was done to the five scheduled plots on September 18, 1987. A front crossed the site during late morning, producing nearby rain showers but not on the study area. Burning conditions were marginal when the first plot (Block V) was ignited at 1245 but improved steadily during the afternoon. At ignition, ambient temperature and relative humidity were 86°F and 59 percent, respectively, and wind speed was 3-4 mph with gusts to 8 mph. Burning conditions peaked at 1600, when the temperature reached a maximum of 92°F, relative humidity stood at 42 percent, and winds were fairly steady at 5-6 mph. Moisture contents ranged from 6 to 9 percent in the upper litter layer and from 13 to 15 percent in the herbicide-treated hardwood foliage. The nearest fire weather station (about 7 mi distant) recorded a 1-h timelag fuel moisture of 9.5, a 10-h timelag fuel moisture of 9.0, and a fuel stick reading of 9. The Keetch-Byram Drought Index stood at 617, indicating the area was in severe drought. Plots were first backfired and then ringed to produce hot fires. Fuel loading varied from virtually none to jackpots of several tons. Because of the wide variation in fuel loading and the firing techniques used, rates of spread were not methodically taken but spot measurements showed that they often exceeded 1 ft/min. Flame lengths of 6 inches to 3 ft were common except in jackpots, where were they ranged up to 10 ft. Small areas on all plots contained thick, weedy growth that did not burn well. These patches and other areas the fire did not reach because of fuel discontinuites were ignited on September 19, so that 80-90 percent of each plot area was burned. All burns met the intended treatment objectives; results on Blocks II and III were judged excellent.

The chopped area received a single pass with an offset drum chopper pulled by a rubber-tired skidder.

Improved loblolly pine seedlings from the Georgia Forestry Commission nursery were hand planted on all treatment areas in February 1988 at a spacing of approximately 10 x 6 ft (726 trees/ac). Numbered tags were placed on pins set near each of the 140-150 planted seedlings in a 0.2-ac measurement plot. All volunteer seedlings were removed from measurement plots at the time of planting. Survival, height, and diameter (1.0 ft aboveground) of the planted pines were measured in October 1988 (survival and height only), January 1990, and October 1990.

Herbs, shrubs, vines, and trees less than 4.6 ft tall were observed on 10 permanent milacre plots per treatment plot. The 10 milacres were located on a line tangent to the 0.2-ac circular plot. The line was oriented in the plot to run perpendicular to the slope, and the milacres were 10 ft apart along the line. Coverages by vines, weeds, and grasses were estimated as percentages of the milacre. The total coverage for these three groups could exceed 100 percent due to layering of the vegetation. Also,

y, a species had to cover 10 percent or more of the area. For each iden-fied plant, the percent cover was estimated.

The SAS/STAT (1987) software program for personal computers was used to alyze the data. Treatment means were separated with the Duncan's multi-e range test when analyses of variance showed significant treatment dif-rences at the 0.05 level of probability.

Results And Discussion

No significant difference in the survival of planted seedlings was und among site preparation treatments. After one, two, and three growing asons overall survival was 69, 68, and 67 percent, respectively (Table . Thus, the greatest seedling mortality occurred from the time of plant-g in February 1988 until January 1989, when initial survival counts were corded. A severe drought in the spring and early summer of 1988 was un-ubtedly responsible for much of the mortality. Once established, howev-, planted seedlings on all plots maintained a stocking level of approxi-tely 500 trees/ac for the next 2 years.

After the first growing season the heights of planted seedlings in the own-and-burn area were significantly taller than those in the chopped or ntrol areas (Table 1). By the end of the second growing season, seed-ngs on the brown-and-burn area were significantly taller than all other edlings. By the end of the third growing season, the mean heights of edlings in all treatments were significantly different: average heights re 5.98 ft on brown-and-burn area, 5.17 ft on the herbicide-only area, 59 ft on the chopped area, 4.00 ft on the control plots.

The diameter growth response of seedlings to treatment was similar to e height growth response. After two growing seasons, the mean diameter the seedlings in the brown-and-burn areas was significantly greater than at of seedlings on any other areas (Table 1). After three growing seas-s, the seedling diameters in the brown-and-burn area averaged 1.02 inches mpared with 0.76 inch for the herbicide-only area, 0.72 inch for the opped area, and 0.47 inch for the control area.

A seedling volume index can be computed by squaring the diameter and ltiplying by the height. This value is useful for comparing pine seed-ng response growth among the treatment effects. For the 2 years with ameter measurements, the volume index after the brown-and-burn treatment s significantly greater than after any other site preparation treatment able 1). Both herbicide alone and the chopping also increased seedling owth over that of controls. The magnitude of the difference among treat-nts is striking. After three growing seasons, the volume index for seed-ngs in the brown-and-burn areas was more than six times that on the con-ol area and more than twice that of the chopped area.

The outstanding response to the brown-and-burn treatment appeared to be a nction of reduced competition during the first 3 years after planting.

Table 1. Survival, height, diameter, and volume index of loblolly pine seedlings planted on four site preparation treatments in the Georgia Piedmont.

Treatment	Year 1	Year 2	Year 3
	-------- Survival (percent) ------		
Brown and burn	71.87 a[1]	70.63 a	70.50 a
Herbicide only	65.18 a	64.02 a	62.88 a
Drum chopping	67.72 a	67.03 a	66.08 a
Control	73.61 a	71.48 a	69.22 a
	----------- Height (ft) -------------		
Brown and Burn	1.16 a	3.52 a	5.98 a
Herbicide only	1.10 ab	2.89 b	5.17 b
Drum chopping	1.03 b	2.62 bc	4.59 c
Control	1.03 b	2.31 c	4.00 d
	-------- Diameter (inches) ---------		
Brown and burn	--	0.59 a	1.02 a
Herbicide only	--	0.41 b	0.76 b
Chopping	--	0.39 b	0.72 b
Control	--	0.28 c	0.47 c
	------ Volume index ($inches^3$) -----		
Brown and burn	--	21.88 a	102.99 a
Herbicide only	--	8.74 b	53.57 b
Drum chopping	--	7.27 b	43.39 c
Control	--	2.94 c	16.39 d

[1] Values with different letters within the same year are significantly different at the 0.05 level of probability.

Data from the 10 milacre samples per treatment plot in year 1 indicated that the percent cover of vines was significantly reduced on both the brown and burn plots and the herbicide only plots as compared to the chop treatment area or the control (Table 2). The pattern of increased vine competition on the chopped and control plots held for the next 2 years, but all plots showed an increase in the percent of vine cover from years 1 to 3.

Table 2. Percent cover of weeds and grasses and vines on milacre plots on areas with four site preparation treatments.

Treatment	Year 1	Year 2	Year 3
	-------------(percent cover)	--------------	
		Weeds and grasses	
Brown and burn	52.56 b[1]	66.72 a	53.80 a
Herbicide only	64.04 a	8.78 a	53.14 a
Drum chopping	43.74 b	61.74 a	40.76 ab
Control	44.78 b	45.90 b	31.74 b
		Vines	
Brown and burn	19.18 b	39.28 c	33.68 c
Herbicide only	20.44 b	52.04 b	50.24 b
Drum chopping	56.52 a	78.02 ab	71.48 a
Control	53.30 a	84.10 ab	76.12 a

[1] Values with different letters within the same year are significantly different at the 0.05 level of probability.

In contrast, weed and grass species had a greater percent cover on the erbicide-only and brown-and-burn areas (Table 2). The herbicide-alone ean value in year 1 was significantly greater than those of the other ree treatments. In year 2, the control treatment had a significantly wer percent cover value. In year 3, the brown-and-burn and herbicide-one areas had significantly higher cover percentages than the control ea, but they were not different from the chopped area.

Thus, weed and grass coverage was inversely proportional to the vine verage. When vines were reduced by herbicide or herbicide and burning, e earlier species of plant succession are favored for 2 or 3 years. anted pines compete more successfully with grasses than they do with nes and they grow faster in both height and diameter under the former nditions.

Individual plant species were recorded on each milacre plot when they cupied more than 10 percent of the area. The frequency and percent cover r important species were affect by site preparation treatments. For ex- ple, fireweed (Eupatorium album L.) is an aggressive pioneer species and s most prevalent after brown-and-burn or herbicide-only treatments (Table). In year 1, fireweed was identified on 80 percent of the brown and burn ots and 44 percent of the herbicide plots. However, only 2 percent of e chopped plots and none of the control plots had fireweed listed as an portant species. In year 2, the percent of milacres with fireweed de- eased to 2 and 6 percent in the brown-and-burn plots and herbicide-only

plots, respectively. Fireweed completely disappeared by year three on all plots. It was never observed as an important species on the control plots.

Table 3. Percent of milacres with indicator species, and the average milacre coverage for four site preparation treatments in the Georgia Piedmont.

Treatment	Year 1		Year 2		Year 3	
	Present	Cover	Present	Cover	Present	Cover
	(percent)					
			Fireweed			
Brown and burn	80	31	2	23	0	0
Herbicide only	44	27	6	22	0	0
Drum chopping	2	10	0	0	0	0
Control	0	0	0	0	0	0
			Broomsedge			
Brown and burn	8	29	12	32	32	35
Herbicide only	30	22	56	37	60	38
Drum chopping	12	16	30	24	30	20
Control	8	21	28	20	22	25
			Panicums			
Brown and burn	18	21	50	37	52	33
Herbicide only	34	28	42	35	26	23
Drum chopping	14	35	20	26	14	29
Control	28	17	32	39	22	32
			Honeysuckle			
Brown and burn	14	47	38	55	52	46
Herbicide only	54	32	80	64	80	61
Drum chopping	82	58	100	76	92	74
Control	90	52	100	79	98	74

Other important species, such as broomsedge (<u>Andropogon virginicus</u> L.) and panicum grasses (<u>Panicum</u> spp.), were prevalent after all treatments and their occurrence was not related to the method of site preparation.

Broomsedge appeared to be favored by the herbicide-only treatment. Tordon 101 contains 2,4-D, which kills broadleaf weeds. Panicums were broadly found across all treated areas, but were not frequent on the brown-and-burn plots in years 2 and 3. This species invades disturbed sites and is favored by treatments that produce areas of bare soil. The presence of honeysuckle (Lonicera japonica Thunb.) was greatly reduced on the brown-and-burn plots in year 1 (14 percent), but its occurrence gradually increased to 52 percent of the plots by year 3. In contrast, both the chopped area and the control area had a high frequency of honeysuckle in year 1 (82 and 90 percent, respectively) and reached 100 percent occurrence by year 2 (Table 3). When present, honeysuckle tended to occupy a relatively large percentage of the site. For example, on control milacres honeysuckle coverage averaged 79 percent in year 2 and 74 percent cover in year 3.

The number of hardwood sprouts on the 0.02-ac plots was not significantly affected by site preparation method after three growing seasons. Sprout prevalence did not appear to be affected by treatment.

Conclusions

Planted loblolly pine responded very positively to a postharvest site preparation combination of herbicide and burning. Herbicide alone and mechanical treatment also increased seedling growth.

Pioneer plant species were favored by the brown-and-burn and herbicide-only treatments. For example, fireweed was prevalent the first 2 years after site preparation but disappeared from the plots by year 3. In contrast, vines were most prevalent after chopping and on untreated control areas. Vine coverage increased on the mechanical and control areas and by year 3 were the major species group on the plots.

When NIPF landowners harvest pine without a regeneration plan and the site is not adequately stocked with advance regeneration, the brown-and-burn site preparation method can be effectively used to establish a fast-growing pine plantation.

Acknowledgments

The authors acknowledge Fred Allen, Lynn Hooven, and Walker Rivers of the Georgia Forestry Commission who supported the study with financial assistance and equipment.

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EVALUATION OF SIX SITE-PREPARATION TREATMENTS ON GROWTH AND SURVIVAL OF LOBLOLLY PINE IN THE GEORGIA PIEDMONT [1]

M. Boyd Edwards and Barry D. Shiver [2]

Abstract. Six site-preparation treatments that ranged in intensity from check (no active treatment) to shear-rootrake-burn-disk-fertilizer-herbicide were applied in replicated 2-ac plots on the Hitchiti Experimental Forest on a Piedmont site in central Georgia. Loblolly pine (Pinus taeda L.) seedlings were planted and their survival, height, and diameter growth observed for 8 years. Rates of survival and growth were lower for pines in the check plots than for any others. Treatments that included mechanical tilling resulted in good growth and survival. The most productive plots were those that were treated with fertilizer and herbicide in combination; these yielded almost 3.8 times as much volume/ac as the check plots did.

Introduction

Few long-term studies have sessed the effectiveness of dif- :ent site-preparation treatments increasing the survival and owth of planted loblolly pine (Pi- s taeda L.) in the Piedmont Prov- :e. This study describes the ef- :ts of six site-preparation eatments of different intensities survival and growth of planted blolly pine in the Piedmont of orgia after 8 growing seasons. e information presented here will lp foresters, land managers, and ivate landowners in the Piedmont select site-preparation treatments that will minimize loblolly pine mortality and maximize yield.

Methods

The study area is an 84-ac tract located in the Hitchiti Experimental Forest, 20 mi north of Macon, Georgia, in Jones County. The harvested stand was composed mainly of loblolly pine, but some mature and sapling-sized sweetgum (Liquidambar styraciflua L.) and dogwood (Cornus florida L.) and other hardwoods were present. Average site index for loblolly pine was 80 ft at 50 years. The preharvest stand was regenerated naturally on eroded cotton fields that were abandoned in the 1930s, after boll weevil epidemic and economic depression. The soils are comprised of five series which occurred as eroded phases on this undulating terrain, and are typical Piedmont clayey Ultisols except for

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Paper presented at Sixth Biennial ıthern Silvicultural Research Con- :ence, Memphis, TN, Oct. 30-Nov. 1990.

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alluviated soils on the lower slopes:

a.	Cecil	clayey kaolinitic thermic	Typic Hapludults
b.	Davidson	clayey kaolinitic thermic	Rhodic Paleudults
c.	Vance	clayey mixed thermic	Typic Hapludults
d.	Wilkes	loamy mixed thermic	Typic Hapludalfs
e.	Congaree	fine-loamy mixed, nonacid thermic	Typic Udifluvents

Three broad ridges run generally to the Southeast from a main curving ridge that is the site's west and northwest boundary. Wilkes series soils occur on the long slopes, Congaree series occur along streams, and Cecil, Davidson, and Vance series are on the uplands. The two intermittent streams separating the ridges have broad, flat stream-side zones that drain into a perennial stream forming the site's south and southwest boundaries.

The merchantable pines were harvested in the spring of 1980. Hardwoods were not removed at that time. The site lay fallow for a year and the study was established in the spring of 1981. The study was designed as a randomized complete block experiment; each treatment plot comprised 2 ac, and each of the six treatments was replicated five times.

The five blocks were located by topographic position. Two blocks were on well-drained ridges, two were positioned on side slopes, and one was located along the upland portions of an intermittent gulley and stream system. Within each block, two to three soil series occurred. Although these series were similar, there was much variation in surface texture and organic matter within the study area.

The site preparation treatments are listed below in order of increasing intensity.

1. Clearcut only (check)--No site preparation.
2. Chainsaw--All residual trees greater than 1 inch dbh were felled with a chainsaw in August 1981.
3. Shear and chop--Shearing was performed with a D7-sized tractor and a KG-blade in September 1981. Chopping was done with a single pass of a single-drum chopper. Application was from September to November 1981. No burning was performed on treatments 3 and 4 due to unsuitable weather conditions.
4. Shear, chop, and herbicide--In addition to the shearing and chopping of treatment 3, 0.5 cc Velpar Gridball™ pellets (hexazinone) with 10 percent a.i. were applied in a 1.9- x 1.9-ft^2 grid at a rate of 25 lb/ac in March 1982.
5. Shear, rootrake, burn, and disk--Shearing and rootraking into windrows was carried out in September 1981. Good burns of the windrows were achieved in October 1981. The remaining debris and ash were scattered over the plots with a dozer blade, then the plots were disked with an offset harrow to a depth of 6 to 8 inches in October 1981.

(34-0-0) was applied by hand at rate of 300 lb/ac in March 1983 and Oust™ weed killer, containing 75 percent sulfometuron methyl, was applied at a rate of 8 oz/ac in April, with backpack sprayers. Herbaceous weed control was essentially 100 percent during most of the 1983 growing season.

Improved loblolly pine seedlings (1-0 stock) were obtained from the rgia Forestry Commission nursery. They were hand-planted with dibble s in January and February 1982 on a spacing of 6 x 10 ft.

Measurements were made for 5 consecutive years and again after the hth growing season. Measurements included heights of seedlings and ng saplings. Diameters were measured at the 1-ft height after the third wing season and at breast height after the fourth growing season. Anal- s of variance procedures were used to test for significant by-treatment ferences in height, diameter, percentage survival, and volume growth. can's multiple range test was used to determine whether differences ng means were significant at the 0.05 level. All data analyses were formed using the Statistical Analysis System (SAS 1985).

Results And Discussion

Response in rate of survival was critical; growth responses would have n less meaningful if survival had varied widely among treatments. At end of the first growing season, treatment 4 was the only one that gave vival rates significantly different from those in the check plots (Table Survival in treatment 4 plots was reduced because very heavy rain fell t after the pelleted herbicide was applied. Approximately 3 inches of n fell in about 3½ hours, and this resulted in rapid distribution of a ge quantity of herbicide.

About 35 percent of the planted pines were killed, and there was almost al first-year control of herbaceous and woody plants. Replacement pines e planted the following winter. Approximately 80 percent of the ground the plots was bare during the 1982 growing season and about 20 percent ained bare ground after 8 years.

After five growing seasons, survival for all treatments exceeded that the check (no site preparation). The survival data demonstrate two ious trends:

. Initial survival increases gradually and progressively with increasing level of site preparation;
. Mortality of established seedlings is greater with the low intensity site-preparation treatments.

The data also demonstrate that the most critical period for survival is first growing season after planting. At 2 years after planting there no change in survival rates except for the shear, chop, and herbicide atment. This change reflected the replacement of pines killed by

herbicide. Significant changes in survival were noted after the third, fourth, and fifth growing seasons. The more intensive treatments resulted in the highest rates of survival for established seedlings. This may be due to reduction of competition by chopping, disking, and use of herbicides, and to a short-term increase in available nutrients. The two treatments that included disking yielded the highest rates of survival. This is consistent with results of a study at B.F. Grant Forest, Athens, Georgia, where site-preparation with shearing, rootraking, and disking resulted in an average of 90 percent survival at age 4 (Dr. Barry Shiver, personal communication). It appears that disking improves chances for pine survival by increasing the depth of the rooting zone and the production of more adventitous roots. Disking also has been shown to decrease the bulk density of the soil, thereby increasing soil porosity and the potential water availability to the seedlings. This is important because increased water availability also increases availability of nutrients to the seedlings and may result in better growth.

Table 1. Loblolly pine survival for 1, 2, 3, 4, 5, and 8 years after re-establishment with six site-preparation treatments.

	Survival after:					
Treatment[1]	1 yr	2 yr	3 yr	4 yr	5 yr	8 yr
	(percent)					
1	92 a[2]	92 a	89 c	87 b	84 c	77 c
2	94 a	92 a	91 bc	89 b	88 bc	80 bc
3	93 a	92 a	92 bc	91 ab	90 abc	87 abc
4	64 b	95 a	95 ab	94 ab	94 ab	92 ab
5	98 a	98 a	98 a	98 a	97 a	96 a
6	98 a	98 a	97 ab	97 a	97 a	93 ab

[1] 1 = Clearcut only
2 = Chainsaw
3 = Shear and chop
4 = Shear, chop and herbicide
5 = Shear, windrow, burn, and disk
6 = Shear, windrow, burn, disk, fertilize, and apply herbicide

[2] Within growing season, means followed by the same letter are not significantly different (P = 0.05).

After eight growing seasons, survival for all treatments still exceed that for the check, which had declined to 77 percent. Percent survival continued to increase gradually with increasing intensity of site preparation. For the first time during the study, one treatment was significantly better than the others in terms of survival. Survival for treatment

with shear, windrow, burn and disk declined only 1 percent between years
and 8, while survival for treatment 6, which included fertilizer and her-
cide declined 4 percent (to 93 percent) during the period. The small de-
ine in the treatment-6 plots is thought to be due to the death of smaller
ees during the extreme drought of 1986, although this cannot be substan-
ated. This is probably a case of statistical significance rather than
actical significance because both treatments still show excellent levels
survival for eight growing seasons.

After the second and third growing seasons, seedling height and height owth differed significantly among treatments (Table 2), with the excep- on of treatment 4. All site-preparation treatments resulted in increased tal seedling height and height growth. Greatest total height and height owth occurred in treatment 6, which included herbicide application that ovided essentially 100 percent herbaceous weed control plus fertilizer d disking.

ble 2. Effects of site-preparation treatment on mean seedling height and height growth for years 1-5, d 8 years after establishment.

eatment[1]	1 yr Ht	2 yr Ht	2 yr Growth	3 yr Ht	3 yr Growth	4 yr Ht	4 yr Growth	5 yr Ht	5 yr Growth	8 yr Ht	8 yr Growth
	(ft)										
1	1.1a[2]	2.1bc	1.0c	3.5c	1.4d	5.8c	2.3c	7.8c	2.0c	15.8c	8.0c
2	1.2a	2.3b	1.1bc	4.4bc	2.1bc	6.6bc	2.2c	9.0bc	2.4bc	18.7bc	9.7b
3	1.1a	2.4ab	1.3b	4.8b	2.4b	7.7b	2.9ab	10.2b	2.5ab	21.4ab	11.2ab
4	1.0a	1.6c	0.6c	3.4c	1.8cd	5.7c	2.3bc	8.1c	2.4b	17.9c	9.8b
5	1.0a	2.2a	1.2bc	4.8b	2.6b	7.6b	2.8ab	10.3b	2.7ab	22.1a	11.8a
6	1.1a	2.9a	1.8a	6.3a	3.4a	9.5a	3.2a	12.4a	2.9a	24.2a	11.8a

1 = Clearcut only
2 = Chainsaw
3 = Shear and chop
4 = Shear, chop, and apply herbicide
5 = Shear, windrow, burn, and disk
6 = Shear, windrow, burn, disk, fertilize, and apply herbicide

Within growing season, means followed by the same letter are not significantly different (P = 0.05).

Greater average tree height was associated with increasing intensity of eatment through the eighth growing season, when heights for all treat- nts exceeded those for the check plots. Height of pines on the check ots increased, from 7.8 to 15.8 ft from age 5 to 8; while treatment 6, e best treatment in terms of total height and height growth, increased om 12.4 to 24.2 ft. In general, all treatments approximately doubled eir heights between ages 5 and 8. It is interesting that treatment 3 hear and chop) showed a significant increase in height, from 10.2 to 21.4 and is the third best treatment after 8 growing seasons. This treatment presents standard site preparation on many sites today.

After four growing seasons, diameters of individual trees could be measured at breast height, and this made it possible to compare by-treatment total volumes (Table 3). Except in the case of treatment 4, where the trees were of two ages, more intensive treatments were still associated with greater mean dbh and total volume after five and eight growing seasons. The data for volume growth per acre after five and eight growing seasons tell the story for this study at the present (Table 4).

Table 3. Effects of site-preparation on average tree size after four and five growing seasons.

Treatment[1]	Height 4th	Height 5th	Dbh 4th	Dbh 5th	Volume 4th	Volume 5th
	--- (ft) ---		--- (inches) ---		---- (ft^3) ---	
1	5.8c[2]	7.8c	0.5c	0.8d	0.02c	0.05c
2	6.6bc	9.0bc	0.7bc	1.1cd	0.03bc	0.09bc
3	7.7b	10.2b	0.9b	1.5b	0.06b	0.15b
4	5.7c	8.1c	0.8b	1.2bc	0.05b	0.12b
5	7.6b	10.3b	0.9b	1.5b	0.05b	0.15b
6	9.5a	12.4a	1.2a	1.9a	0.09a	0.25a

[1] 1 = Clearcut only
2 = Chainsaw
3 = Shear and chop
4 = Shear, chop, and apply herbicide
5 = Shear, windrow, burn, and disk
6 = Shear, windrow, burn, disk, fertilize, and apply herbicide

[2] Within growing seasons, means followed by the same letter are not significantly different (P = 0.05).

Tillage appears to contribute significantly to growth. All treatments that included tillage (treatments 3, 4, 5, and 6) resulted in greater total volume after five and eight growing seasons than those that did not. Even though treatment-4 plots (shear, chop, herbicide) contained trees of two ages, the mean height, mean dbh, and volume figures for those plots exceed the corresponding figures for nontilled plots (treatment 1 and 2). Five years after planting, total volumes in plots that were disked and plots that were chopped were similar (treatments 3, 4, and 5). After five growing seasons, volume was 61 percent greater in the treatment-6 plots than in the treatment-5 plots. Because the treatment-5 and treatment-6 plots were tilled in the same way, this difference in volume must be attributed to the application of herbicide and fertilizer to the treatment-6 plots. Even so, treatment-5 plots produced five times as much volume as control plots produced, which gives some indication of the value of intensive mechanical site preparation.

Table 4. Mean volume per acre after five and eight growing seasons and mean volume growth from end of fifth to end of eighth growing season by treatment.

Treatment[1]	Volume/ac 5 yr	Volume/ac 8 yr	Growth
	---------------- (ft^3)	----------------	----------------
1	15.93d[2]	149.75c	133.82c
2	31.74cd	227.79c	196.05c
3	63.83bc	464.38b	400.55b
4	52.53bcd	430.55b	378.02b
5	75.63b	594.43ab	518.80ab
6	121.93a	716.05a	594.12a

[1] 1 = Clearcut only
2 = Chainsaw
3 = Shear and chop
4 = Shear, chop, and apply herbicide
5 = Shear, windrow, burn, and disk
6 = Shear, windrow, burn, disk, fertilize, and apply herbicide

[2] Within growing season, means followed by the same letter are not significantly different (P = 0.05).

Treatment 6 had 21 percent more volume than treatment 5, which indi-tes that additional treatment with fertilization and weed control were ill providing additional growth. The most intensive treatment, treatment yielded almost 3.8 times as much volume as the check after eight growing asons.

Early growth of the young pines was moderately impacted by the Nantuc-t pine tipmoth (Rhyacionia frustrana Comstock). At the end of the first owing season, 5 percent of the seedlings showed damage by this pest (Ed-rds 1990). There was no definite pattern of infestation by treatment, l the range began at 2 percent of shear, chop, and herbicide (treatment seedlings which showed the lowest incidence and was the only treatment low that of the 5 percent infestation of the check (treatment 1). How-er, this treatment was the one which had the highest rate of mortality e to herbicide action. The treatment with the highest incidence of in-station at the end of the first growing season was shear, windrow, burn l disk with 8 percent. At the end of the second growing season the in-lence of occurrence increased to 17 percent of all the seedlings, with e lowest being the chainsaw treatment. It was the only treatment with ss infestation than the control. All other treatments equalled or sur-ssed that of the control with the shear, windrow, burn and disk treatment owing highest rate of infestation again. At the end of the third growing ason, the seedlings had progressed to the sapling stage and little or no mage was observed.

At the end of the fifth growing season, 6 percent of the young pines showed signs of rust infection [Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme]. There was no clear pattern of infestation by treatment, and no treatment exceeded the infestation rate of the check. These findings differ from those reported by Burton et al. (1985), who found that rust infection increased with an increase in site preparation intensity. The rate of rust infection in our study plots is low and is not expected to have a major impact on future yields.

In summary, the more intensive site-preparation treatments produced the highest survival rates at the end of eight growing seasons. The shear, pile, burn and disk treatment (treatment 5) was signficiantly better than the others. Additional site preparation with weed control and fertilizer did not benefit pine survival at age 8. Disking was particularly beneficial, and probably increased pine survival by allowing roots to penetrate deeper into the soil. The study shows that even less intensive site-preparation treatments increased survival rates; even the survival on the chainsaw treatment plots (treatment 2) exceeded that in the check plots. This level of improvement would be statisfactory to many small landowners. Heights and diameters increased gradually as intensity of site preparation increased. In general, heights, and dbh doubled during the period from age 5 to 8 years. At the end of eight growing seasons, volume per acre for the most intensive treatment was 3.8 times more than for the check, and all site-preparation treatments resulted in more growth than the check. Site preparation with fertilizer and weed control (treatment 6) yielded 21 percent more volume growth at the end of eight growing seasons than the same treatment (treatment 5).

We have not finally determined what combination of site-preparation treatments will result in greatest survival and growth of loblolly pine in the Piedmont. This study is being continued and expanded to provide information that will increase our understanding of site-preparation benefits.

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HERBICIDE, FERTILIZER, AND SHADE INFLUENCE LOBLOLLY PINE GROWTH AND SURVIVAL ON HARSH TEXAS SITES [1]

Michael G. Messina [2]

Abstract. A study was initiated on deep sandy soils (Tonkawa series) in northeast Texas to determine influences of herbicide, fertilizer, and artificial shade on the growth and survival of loblolly pine (*Pinus taeda* L.) seedlings. A 2x2x2 factorial was established. Thirty-tree plots were hand-planted with 1-0 drought-hardy seedlings which were individually fertilized with a blended fertilizer. Herbaceous competition was controlled with glyphosate and artificial shade was supplied with tree shades. All three treatments significantly ($P < 0.05$) affected survival and accounted for 85 percent of the variation in survival. Herbicide and shade effects were positive but fertilizer effects were negative. The overall mean survival was very low at 27 percent. The mean percent survival for each treatment was: shade 40 percent, herbicide 35 percent, and fertilizer 21 percent. The best survival was afforded by a combined herbicide/shade treatment without fertilizer (56 percent). Although shade afforded the best survival advantage, treatment influenced biomass production in the following order: herbicide > fertilizer = shade. Shoot/root ratios were produced as: fertilizer > shade > herbicide; and leaf areas as herbicide > shade > fertilizer.

Introduction

Several areas totaling about 23 thousand acres within the Piney Woods region of northeast Texas contain very droughty, deep sandy soils (Typic Quartzipsamments; Tonkawa series) characterized by low fertility, high acidity, and high permeability. In some areas, these soils cover more than 2 thousand acres. Tonkawa soils were formed in sandy deposits and are usually on upland sites with slopes ranging from 0 to 20 percent. The soil is a fine sand to a depth of 80 inches or more. Typical site index for loblolly pine is 55 feet (50-year base). Under natural conditions, the dominant species is sandjack (bluejack) oak (*Quercus incana* Bart.) with some shortleaf pine (*Pinus echinata* Mill.) and longleaf pine (*P. palustris* Mill.) intermixed (Dolezel 1980).

From 1973 to 1975, about 5 thousand acres of this region were clearcut and burned for pine plantation establishment (Kroll et al. 1985). Such intense site preparation created an essentially bare sand surface subject to environmental extremes that produced a very harsh site for seedling development. At least three pine species and several planting methods have been tested since then with very limited success. Much of the clearcut acreage remains without regeneration.

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30 -Nov. 1, 1990.

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A study was installed in February 1987 to determine the relative influences of specific management practices and environment on the growth and survival of planted loblolly pine seedlings on the Tonkawa series.

Materials And Methods

A study site was located approximately 6 mi west of Garrison, Nacogdoches County, Texas. A 2x2x2 factorial design of herbicide, fertilizer, and artificial shade replicated eight times was established (i.e., eight treatments in eight reps, or 64 plots). Plots 24x80 ft in size and containing 30 trees each were hand-planted on February 14, 1987, at an 8x8-ft spacing with 1-0 bare-root loblolly pine. The seedlings were purchased from the Texas Forest Service's (TFS) Indian Mounds Nursery near Alto, and were developed from a TFS tree improvement program for drought-hardiness. The seedlings were dipped in Terra-Sorb™ and deep planted with half of the shoot buried to limit transpirational water loss. Terra-Sorb is a gelatinized, starch-hydrolyzed copolymer mixed with water to form a substance for increasing moisture holding capacity.

Seedlings were individually fertilized about 3 weeks after planting with 3.5 oz of a 12-24-12 blended fertilizer placed in a spade slit approximately 6 inches from the seedling. This method was used to limit fertilizer loss through possible volatilization and to discourage competing vegetation. Herbaceous competition was controlled with glyphosate herbicide initially broadcast over entire plots at a rate of 24 oz/ac using backpack sprayers in March 1987. Thereafter, glyphosate was applied at the same rate to 6-ft diameter circles around each seedling in July 1987 and in May 1988. Artificial shade was supplied with polyolefin tree shades (International Reforestation Suppliers, Eugene, Oregon) on wire wickets placed against the seedlings on their south-southwest side. The tree shades measured approximately 8-inches wide x 12-inches tall and were oriented perpendicular to the direction of the sun during the midday period. The shades provided approximately 80 percent shade.

Extensive animal predation (likely rabbits) in some plots occurred soon after planting when the seedlings were the only green vegetation on the plots. This necessitated a replanting of the affected plots on March 6, 1987. All seedlings were treated at that time with an ammonium-based animal repellant which retarded predation until the herbaceous vegetation greened sufficiently to lessen pressure on the seedlings. Woody vegetation (mostly sandjack oak) was also treated on March 6 on an individual plant basis with triclopyr herbicide (Garlon 4™) to eliminate the shading and water competition effects of sprout clumps.

Survival was measured monthly through most of the 1987 (March-September) and 1988 (May-October) growing seasons. It was presumed that most seedling mortality would occur during the more stressful warmer months so survival assessment was suspended during the cooler months. After the close of the 1987 growing season (November 14) all seedlings in the study were measured for total height and root collar diameter (RCD). Also on this date, replications 1, 3, 5, and 7 were sacrificed by destructively

ampling three trees per plot for dry weight determination (stem, root and oliage) and leaf area. No further measurements or assessments were conducted in these replications. Measurement of seedling height and RCD after he 1988 growing season occurred on December 22 on the remaining replications (2, 4, 6, and 8) when again three seedlings per plot were destructively sampled for the same determinations as in 1987. The field portion f the study was then terminated.

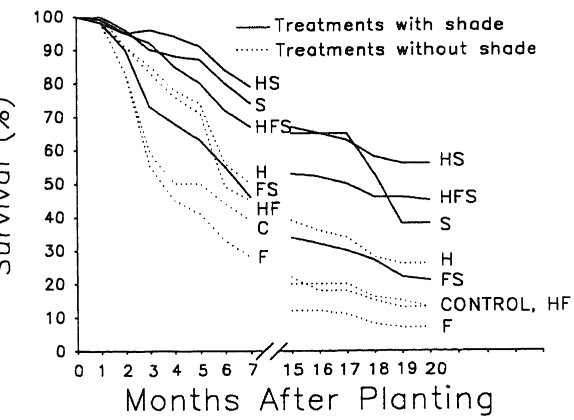
Laboratory analyses concerned dry weights of root, stem, and foliage ortions as well as total seedling leaf area using the methods of Johnson 1984) for total surface leaf area. Seedling foliage nutrient concentraions on the destructively sampled seedlings were assessed both years for otal nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesum (Mg). Nitrogen and P were determined using an AutoAnalyzer, and K, Ca, nd Mg were determined with atomic absorption spectrophotometry.

All mention of statistical significance in the following discussion is t the $\alpha = 0.05$ level unless otherwise stated.

Results And Discussion

urvival

All three treatments (herbicide, fertilization, and shade) significanty ($P < 0.01$) affected two-year (actually 20 months) survival and accounted or 85 percent of the variation in survival. Most of the mortality occured during the first growing season (Fig. 1). Survival decreased at a dereasing rate and became fairly constant by the end of the second growing eason. Mean survival two years after planting was 27 percent, half of the irst year's mean survival of 54 percent (7 months after planting). Figure illustrates a change in ranking of some treatments as time progressed. For example, an initially promising treatment like shade-only suffered substantial mortality during the second summer. The other treatments largely maintained their relative rankings between years.



igure 1. Loblolly pine seedling survival trends over 2 years on the Tonkawa ands as affected by treatment.

Figure 2 shows 2-year survival data by treatment. The only treatments that rendered better than average survival contained shade as a component. The mean 2-year survival for each main treatment effect was (Table 1): shade 40 percent, herbicide 35 percent, and fertilizer 21 percent, with the best single-treatment survival afforded by a combined herbicide/shade/no-fertilizer treatment (56 percent).

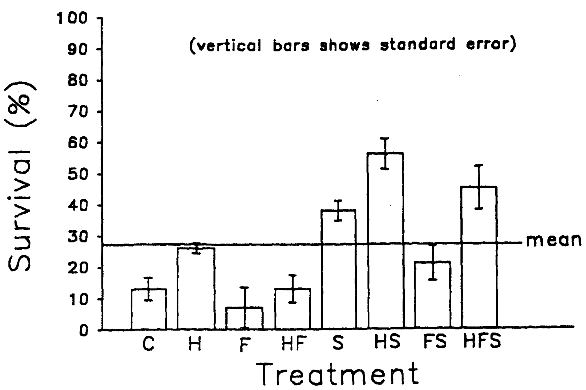


Figure 2. Loblolly pine seedling survival 2 years after planting on the Tonkawa sands as affected by treatment.

The higher survival provided by shade treatments indicates that heat stress was a likely cause of mortality in this study.

Fertilizer had a pronounced negative effect on survival regardless of whether applied alone or in combination with other treatments (Fig. 1 and 2; Table 1). Fertilizer/shade was the only treatment containing shade that yielded less than average survival. It was likely that the very droughty soil conditions caused the fertilizer to be too concentrated near the root zone of the seedlings thereby promoting mortality.

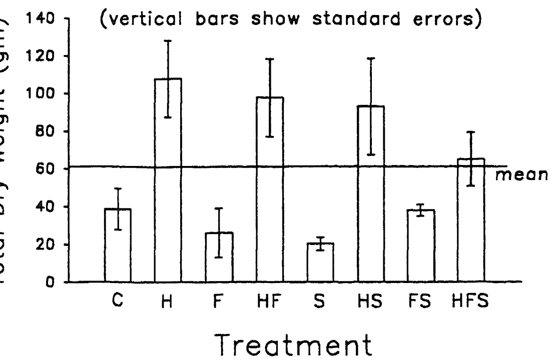
Table 1. Treatment main effects on loblolly pine survival and biomass after 2 years on the Tonkawa sands

Treatment		Survival	Height	RCD	Dry weight	Leaf area
		%	- - - cm	- - -	g	cm^2
Herbicide	with	35 a[1]	56 a	1.4 a	91.0 a	6955 a
	without	20 b	49 b	0.9 b	31.5 b	2315 b
Fertilizer	with	21 a	53 a	1.2 a	61.2 a	4469 a
	without	33 b	53 a	1.2 a	65.1 a	5070 a
Shade	with	40 a	53 a	1.1 a	54.2 a	4363 a
	without	15 b	50 a	1.2 a	73.6 a	5276 a

[1] For a given treatment, means followed by the same letter are not significantly different at the P = 0.05 level.

Growth and Biomass Production

Although shade afforded the best survival, those treatments that included herbicide application showed the greatest total dry weights after 2 years (Fig. 3). This was likely due to an increase in soil water availability after the herbaceous competition reduction. Herbicide application



gure 3. Loblolly pine seedling dry ight 2 years after planting on the ıkawa sands as affected by treatment.

had the greatest influence on seedling dry weight accumulation with herbicide treatments (91.0 g) weighing nearly three times as much as non-herbicide treatments (31.5 g) (Table 1). Fertilizer and shade treatments produced seedlings with considerably lower dry weights and both actually had depressive effects on total dry weight accumulation. Fertilized seedlings accumulated 61.2 g of dry weight after 2 years, whereas non-fertilized trees accumulated 65.1 g. Dry weights of shaded trees were 54.2 g; non-shaded seedlings weighed 73.6 g. However, herbicide was the only treatment at significantly affected dry weight production. The growth depression ised by fertilizer was likely due to the high root zone concentrations ntioned earlier. Shade decreased growth perhaps because loblolly is an colerant species and makes its best growth in full sunlight (Wahlenberg 60).

Shoot/root ratios (shoot = stem + foliage) after two years averaged 24 and varied little across treatments. The lowest ratio was provided by e herbicide/fertilizer/no-shade treatment (2.78); the highest by the ferlizer-only treatment (3.97). Herbicide had the greatest main treatment fect on shoot/root ratio (3.03 with, 3.45 without) with shade (3.19 with, 29 without) and fertilizer (3.24 both with and without) having little or effect.

Root collar diameter after 2 years was affected by treatment to a eater extent than was total seedling height (Fig. 4a and 4b, respective-). Herbicide was the only treatment to significantly affect seedling ight (Table 1). Two-year heights varied, from a low of 43 cm in the ferlizer-only treatment to a high of 59 cm in the herbicide/shade/no-fertizer treatment, with average height being 51 cm. Average RCD was 1.1 cm l varied from 0.7 cm in the shade-only treatment to 1.4 cm in the herbide-only treatment. Figure 4a clearly shows the dominant, significant fluence of herbicide on RCD.

The relatively small seedling dimensions reflect the poor site quality. e data also show the importance of competition reduction to early seedig growth on extremely droughty sites such as this. The plots that ceived herbicide produced significantly greater seedling dry weights, ghts and RCD's after 2 years.

af Area

The leaf areas measured after 2 years were considerably lower than

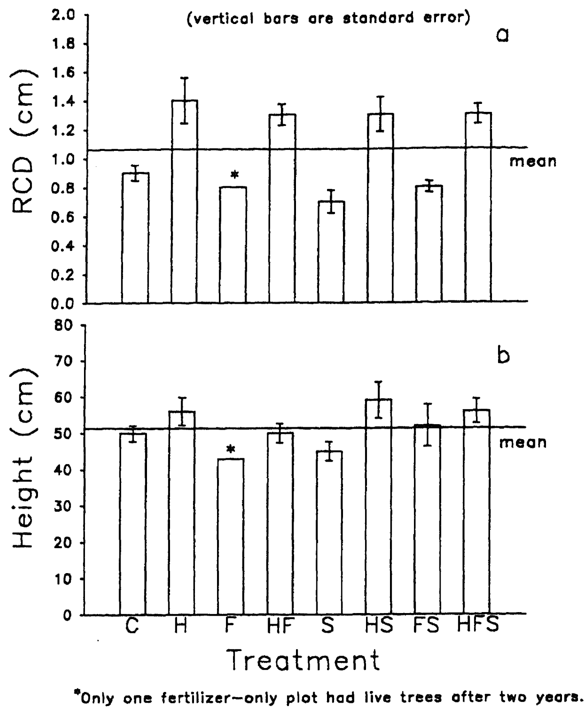


Figure 4. Loblolly pine seedling root collar diameter (a) and height (b) 2 years after planting on the Tonkawa sands as affected by treatment.

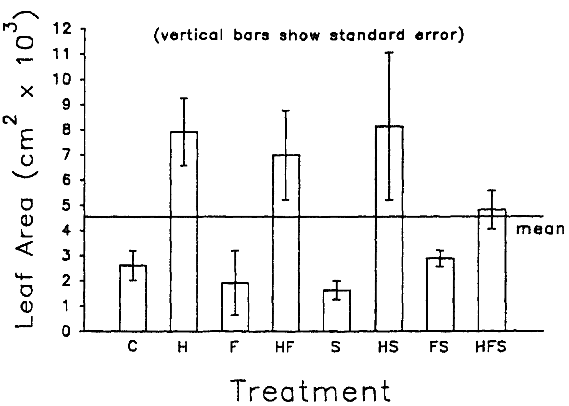


Figure 5. Loblolly pine seedling leaf area 2 years after planting on the Tonkawa sands as affected by treatment.

those reported for 2-year-old loblolly pines elsewhere (Fig. 5) (Zutter et al. 1986). As with the aforementioned biomass and growth results, this reflects the low quality of this site. In addition, many of the leaves were suffering from various forms of herbivory, including town ant (Atta texana Buck.) damage which is fairly prevalent on this type of site (Moser 1984).

The per-tree leaf area averaged 4790 cm^2 over all treatments, but ranged widely from 1637 cm^2 in the shade-only treatment to 8120 cm^2 in the herbicide/shade/no-fertilizer treatment. Herbicide produced the largest variation in leaf area with herbicide treatment seedlings having the greatest mean leaf area and non-herbicide treatments having the lowest mean leaf area, with the difference being threefold (Table 1). Also, herbicide was the only treatment that significantly affected leaf area (Fig. 5; Table 1). As with total seedling dry weight, fertilizer and shade negatively affected leaf area production, albeit not significantly.

Nutrition

Only foliar N concentrations will be discussed here due to the limited scope of this paper. The data on P, K, Ca, and Mg concentrations in foliage, stem and root tissue for both the 1987 and 1988 collections will be supplied by the author upon request.

Foliar N concentrations were not altered greatly by treatment (Table 2).

ncentrations were significantly lower in 1987 (1 year after treatment) an in 1988 (2 years after treatment). Herbicided treatments had sig-ficantly higher foliar N concentrations than non-herbicided treatments. rbicide was the only treatment to significantly alter foliar N concen-ations (Table 2). The significant response of foliar tissue concentra-on to herbicide treatment was likely due to the more favorable soil water nditions in this treatment while the lack of any response to fertilizer y have resulted from the deleterious effects of fertilization which also ad to lower survival and growth.

able 2. Foliar nitrogen concentrations by main effect 1 and 2 years fter treatment (numbers in parentheses are standard errors)

reatment		1987 N	1988 N
		- - - - - percent dry weight	- - - - -
lerbicide	with	1.38 (0.192) a[1]	1.44 (0.098)a
	without	1.24 (0.152) b	1.38 (0.147) b
'ertilizer	with	1.26 (0.165) a	1.40 (0.134) a
	without	1.37 (0.195) a	1.42 (0.122) a
hade	with	1.28 (0.214) a	1.42 (0.091) a
	without	1.34 (0.154) a	1.40 (0.159) a

For a given treatment, means followed by the same letter are not significantly different at the P = 0.05 level.

Conclusions

The importance of soil water status on forest regeneration is obvious, l drought has long been recognized as a controlling factor in success of rest regeneration. However, surface temperature can also be a signifi-nt factor regulating seedling survival. The microclimate of an exposed .l surface such as the one in this study may be extremely harsh for seed-ng growth and survival. While much of the absorbed radiation in a forest lost in evapotranspiration, more radiation in new clearcuts is used for .sing soil and air temperatures. Seedling mortality due to high surface nperatures was likely in this study. Although seedling height and RCD wth, dry weight production, and leaf area were maximized and affected st by herbicide application, artificial shade had the greatest positive fect on survival. This suggests that a moderate degree of overhead shade uld increase seedling survival on similar sites. Understory environments neath forest canopies are much less harsh than clearcut environments be-use much of the total site net radiation is dissipated in the overstory nopy (Holbo and Childs 1987).

The substantial positive effects of herbicide on seedling growth indicate the value of competition reduction to early seedling performance, particularly on droughty sites such as this. Although herbaceous biomass was not quantified, observation revealed a relatively light cover due to the poor site quality. Even so, elimination of this competition resulted in substantial and significant seedling response in both survival and growth. In addition, combining competition control with shade produced the greatest positive effects on survival.

The significant negative effects of fertilization on survival demonstrate the consequence of high fertilizer concentrations too near the seedling rhizosphere. This was the likely cause of the lower survival in fertilized treatments and the nonexistent or negative effects on growth and foliar nutrient concentrations.

Acknowledgments

The author gratefully acknowledges the assistance of the Temple-Inland Corporation, Diboll, Texas, who made land available for this research.

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TOLERANCE OF LOBLOLLY PINE SEEDLINGS TO GLYPHOSATE [1]

James D. Haywood and Thomas W. Melder [2]

Abstract. Broadcasting glyphosate herbicide over loblolly pine (Pinus taeda L.) may provide enough early-season weed control to allow seedlings to establish themselves more rapidly, but glyphosate can injure young trees. To examine the question of seedling injury, four rates of glyphosate were broadcast evenly over planted loblolly pine seedlings, competing vegetation, and plot surface. The rates were 0.42, 0.84, 1.26, and 1.68 kg acid equivalent per hectare (1 pt, 1 qt, 1.5 qt, and 2 qt Roundup™ herbicide per acre). Treatments were made on six separate dates, from April 23 through October 14, of the first growing season. Although glyphosate effectively controlled competing vegetation, all treatments injured the pine seedlings and reduced height growth, and many treatments increased pine mortality.

Introduction

Controlling herbaceous competi- s in young loblolly pine planta- ns can increase seedling survi- , pine diameter, and height wth (Nelson et al., 1981; Creigh- et al., 1987; Haywood and Tiarks 0). Weed control may be espec- ly important when converting pas- e to pine stands (Haywood 1988; ser et al., 1987). The applica- n of herbicides is often the best hod of controlling weeds on for- sites. However, forest managers ll lack sufficient information ut which herbicide to use and the t dates and rates of application.

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aper presented at Sixth Biennial thern Silvicultural Research Con- ence, Memphis, TN, Oct. 30-Nov. 1990.

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Glyphosate herbicide, N-(phosphonomethyl)glycine, is labeled for forestry and is also widely used in agriculture and landscaping and on industrial sites. Glyphosate is usually applied in the fall as a release treatment in pine plantations. Because the year's growing season is almost over, its immediate benefit as a weed control agent is minimal. Because glyphosate is not soil active, it provides no residual weed control the next spring (Haywood 1988). Applying glyphosate earlier in the growing season is a better weed control strategy, but how much seedling injury may result?

To examine the question of seedling injury, four rates of glyphosate, 0.42, 0.84, 1.26, and 1.68 kg acid equivalent per hectare (kg ae/ha) (1 pt, 1, 1.5, and 2 qt Roundup™ herbicide/ac), were broadcast evenly over planted loblolly pine seedlings and competing vegetation. Treatments were made on six dates, from April 23 through October 14 of the first growing season. For

comparison purposes, the labeled rates of glyphosate range from 0.42 to 0.63 kg ae/ha when in tank mixture with sulfometuron methyl for herbaceous weed control and from 1.26 to 1.68 kg ae/ha when applied alone for loblolly pine release in the fall.

Methods

Study Establishment

The study was duplicated on two sites. Site one was a Beauregard silt loam (Plinthaquic, Paleudult, fine-silty, siliceous, thermic) at the J.K. Johnson Tract, Palustris Experimental Forest, Sec. 4, T2N, R3W, Rapides Parish, Louisiana. Site two was a Kolin silt loam (Glossaquic Paleudalf, fine-silty, siliceous, thermic) on the Kisatchie National Forest, Evangeline Ranger District, Compartment 45, Sec. 31, T2N, R2W, Rapides Parish, Louisiana. Both were gently sloping (1-3 percent), moderately well-drained upland sites, but the sites had different cover conditions because of their different management histories.

Site one supported a stand of slash pine (*Pinus elliotii* Engelm. var. *elliotii*). This stand was clearcut in 1973, and the residual trees and logging debris were single chopped with a rolling drum chopper. The vegetation was unrestrained except for periodic controlled burns to reduce fire hazards. Because of burning, vegetation at site one was primarily a heavy rough of bluestem and panicum (*Andropogon* spp. and *Panicum* spp.) grasses, broadleaf weeds (*Rubus* spp.), and scattered sprouts of several typical hardwood species (*Myrica cerifera* L., *Rhus copallina* L., and *Liquidambar styraciflua* L.) at the time of establishment.

Site two was grazed by cattle and supported a stand of loblolly pine (*Pinus taeda* L.). This stand was clearcut in 1980, and the residual trees and logging debris were single chopped with a rolling drum chopper and control burned that fall. Grazing continued, and the vegetation was primarily a low cover of common carpet grass (*Axonopus affinis* Chase), other grasses, broadleaf weeds, and scattered sprouts of several typical hardwood species at the time of establishment.

In January 1982, at both sites, 2-m^2 plots were established in a randomized complete block design with seven blocks. Each block had 30 plots. Plot centers were located on a 3- by 3-m spacing. On each plot, two 1-0 bareroot loblolly pine seedlings were planted about 30-cm apart in the center of the plot. Blocks were established because of site variation and to simplify treatment installation and measurement.

Treatments

Glyphosate in a water solution of 235 L/ha (25 gal/ac) was broadcast evenly over the pine seedlings, competing vegetation, and plot surface. Glyphosate was applied with a hand-pump sprayer. A plastic-lined cylinder was used to delineate the plot perimeter and to prevent drift. At both sites, four concentrations of glyphosate (0.42, 0.84, 1.26, and 1.68 kg ae/ha) were applied on each of the following dates for comparison to untreated checks:

April 23, 1982. Continual rains delayed treatment until this date, and ne soil was very wet. The sky was overcast with high clouds, but it did ot rain. Winds were 8-24 km per hour (kmph) (5-15 mph). The daytime high emperature was 7°C (45°F). Treatments were finished by 11 a.m.

May 19, 1982. Pines were in active height growth. The sky was partly loudy. Winds were 0-8 kmph (0-5 mph). Temperatures ranged from 18°C 55°F) to an afternoon high of 27°C (80°F). Treatments were finished by l:45 a.m.

June 15, 1982. The sky was clear to partly cloudy. Winds were 8-24 kmph 5-15 mph) at site one and 0-8 kmph (0-5 mph) at site two. Temperatures anged from 22°C (72°F) to an afternoon high of 34°C (94°F). Treatments ere finished by 11:45 a.m.

July 15, 1982. The sky was clear to partly cloudy. Winds were 0-2 kmph)-1 mph). Temperatures ranged from 24°C (75°F) to an afternoon high of 5°C (95°F). Treatments were finished by 12:20 p.m.

August 30, 1982. The sky was clear-but-hazy to partly cloudy. Winds ere 0-2 kmph (0-1 mph). Temperatures ranged from 29°C (85°F) to an afernoon high of 36°C (97°F). Treatments were finished by 11:15 a.m.

October 14, 1982. The sky was clear. Winds were 0-2 kmph (0-1 mph). nere was a heavy dew at site two during treatment, but no dew remained by ne time site one was treated. Temperatures ranged from 16°C (60°F) to an fternoon high of 24°C (75°F). Treatments were finished by 11:30 a.m.

easurements And Data Analysis

Before glyphosate was applied, the pine seedlings were examined to deermine if the seedlings were in an active growth stage. In June 1983, eedling heights were taken to the nearest 2.5 cm, and the pines were rated s follows: (1) no evident injury; (2) some injury (0-25 percent); (3) oderate injury (26-50 percent), and; (4) severe injury (more than 50 ercent). Of the original 210 plots per site, 157 plots remained at site ne and 148 plots remained at site two. These plots eventually were lost ecause all the pines died after treatment with glyphosate.

For each site, regression analysis was used to determine the relationnip among seedling survival, height, or injury rating and rate of glyphoate and date of treatment. A polynomial model with a periodic term best escribed these relationships within the range of observations (Bliss 970). The general form of the function follows:

$$Y = b_0 + b_1 (Ra) + b_2(Ra^2) + b_3(D) + b_4(I) + b_5 \{\sin[trans(D)]\} + error,$$

nere

Y = seedling survival, height, or injury rating,
Ra = glyphosate rate,
D = Julian date,
I = rate x date interaction, and
in[trans(D)] = a periodic sine curve relationship where date is first transformed by trans(D) = 2π/365*date.

Glyphosate effectiveness as a weed control agent was determined by periodic inspection of the plots. The competing plant data were not analyzed because of the high efficacy initially obtained with all treatments and the lack of residual control inherent with glyphosate.

Results And Discussion

Pine Survival

Loblolly pine seedling survival was influenced by glyphosate rate and date of treatment (Tables 1 and 2, Fig. 1). At site one, mortality increased when glyphosate was used regardless of rate or date of application although the rates used corresponded to the labeled rates for glyphosate. However, the detrimental effect of chemical use was greater in the summer than in the spring or fall. Seedling survival was also influenced by a rate x date interaction. In the spring, the higher rates of glyphosate were estimated to reduce survival more than the lower rates, but in the fall, differences in survival among glyphosate treatments were no longer important.

At site two, seedling survival was affected by a rate x date interaction (Table 1, Fig. 1). The interaction suggests that survival was adversely influenced in the spring by glyphosate. However, by fall, survival was no longer significantly affected by chemical treatment. This relationship was not a strong one because of a 10.32-percent R^2, a 10-percent probability of a greater $|T|$-value for the interaction coefficient and the actual low number of surviving seedlings after the October treatment (Tables 1 and 2, Fig. 1).

Survival on checks was lowest at site two, possibly because the cattle grazing resulted in animal injury and the close cropped vegetation exposed the seedlings to wind and temperature extremes (Table 1). However, the greater exposure of seedlings to direct contact with glyphosate at site two than at site one apparently did not increase pine mortality when compared with the check treatments.

At both sites, pine survival was generally better after the June 15 glyphosate treatments than after the May 19 and July 15 treatments (Table 1). Unfortunately, higher survival on June 15 could not be explained based on observing the seedlings' general condition (stage of growth or vigor) when treated. Therefore, seedling condition was not useful in predicting loblolly pine survival, although the seedlings are perhaps more tolerant of glyphosate exposure during certain periods in the spring.

Pine Height And Injury

Loblolly seedling height growth and injury rating were adversely affected by glyphosate application regardless of rate (Tables 1 and 2; Fig. 2 and 3). Yeiser and others (1987) also reported reduced height growth after April applications of glyphosate in mixture with sulfometuron methyl when treating herbaceous plant covers.

At site one, estimated average seedling height was greater on the October 14 treatment date than on all other treatment dates, but height growth

Table 1. Loblolly pine seedling survival, height, and injury rating 17 months after planting.

Dates of treatment 1982	Site one Rates (kg ae/ha) None	0.42	0.84	1.26	1.68	Weighted mean	Site two Rates (kg ae/ha) None	0.42	0.84	1.26	1.68	Weighted mean
						Survival (percent)						
April 23	100	71	64	21	36	59	93	71	57	64	21	61
May 19	100	43	14	7	14	36	86	43	29	14	0	34
June 15	100	71	93	57	71	79	64	71	64	64	64	66
July 15	93	71	29	21	0	43	64	57	36	29	7	39
August 30	93	57	50	43	14	51	64	43	71	21	14	43
October 14	93	100	86	93	86	91	86	50	64	64	43	61
Weighted mean	96	69	56	40	37		76	56	54	43	25	
						Height (cm)						
April 23	61	39	30	39	35	42	51	30	27	33	42	36
May 19	55	34	20	30	24	40	47	31	21	34	..	36
June 15	65	44	42	39	39	46	36	42	37	31	36	37
July 15	46	33	34	25	..[1]	6	55	35	41	27	18	41
August 30	62	37	25	30	32	39	56	29	40	26	22	38
October 14	64	54	42	52	41	50	45	48	39	50	37	44
Weighted mean	59	41	34	39	37		49	37	35	34	35	
						Injury rating						
April 23	1.0	3.0	3.4	2.5	3.3	2.6	1.0	2.8	2.8	2.5	2.7	2.3
May 19	1.0	3.0	4.0	3.0	4.0	2.4	1.1	2.5	3.0	3.0	..	2.1
June 15	1.0	2.5	2.4	2.9	2.9	2.3	1.2	1.9	2.6	2.5	2.9	2.3
July 15	1.0	3.4	3.7	4.0	...	2.7	1.1	2.9	2.4	3.3	4.0	2.3
August 30	1.0	3.3	4.0	3.8	4.0	3.0	1.0	3.4	2.9	3.3	4.0	2.7
October 14	1.0	1.8	2.8	2.4	3.0	2.2	1.1	2.1	2.3	2.2	2.5	2.0
Weighted mean	1.0	2.8	3.2	3.1	3.2		1.1	2.5	2.6	2.7	3.0	

[1] Where values are missing, all seedlings died after treatment on all of the blocks.

was nearly completed by fall so less effect was possible (Table 1 and Fig. 2). Seedling height was most adversely affected by summer treatments. At site two, seedling height was also less after the spring treatments than after the fall treatment. The significant adverse effect associated with summer applications of glyphosate at site one was not found at site two (Table 2 and Fig. 2).

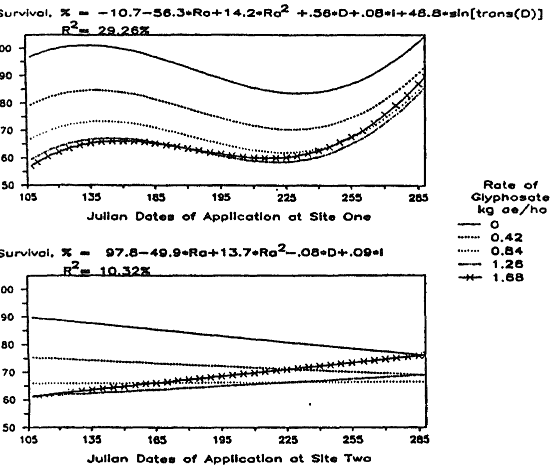
At sites one and two, seedling injury on the October 14 treatment date was less than injury on the other treatment dates, and seedling injury was greater on the summer treatment dates than on the other treatment dates (Tables 1 and 2, and Fig. 3). This finding supported the practice of applying glyphosate in the fall especially at rates greater than 0.42 kg ae/ha.

Weed Control

Glyphosate, regardless of rate, provided 95-percent or better control of the herbaceous plant cover following treatment. High efficacy was expected because in other unpublished work the herbaceous species present were shown to be susceptible to glyphosate.

Table 2. Coefficients for the independent variables and the probabilities of greater |T|-values used to predict survival, height, and injury ratings for sites one and two.

Variables	Coefficient estimate	Prob > |T|
Site One		
Survival, percentage		
Intercept	-10.6745	0.7101
Glyphosate rate	-56.2772	0.0001
(Glyphosate rate)^2	14.23633982	0.0145
Julian date	0.56449919	0.0003
Rate x date interaction)	0.08175951	0.0778
Sin[trans(date)]	48.79473952	0.0001
Height, centimeters		
Intercept	-14.0731	0.4013
Glyphosate rate	-42.7999	0.0001
(Glyphosate rate)^2	18.21129423	0.0001
Julian date	0.38041001	0.0001
Sin[trans(date)]	28.72948901	0.0002
Injury rating		
Intercept	6.02810658	0.0001
Glyphosate rate	3.96091687	0.0001
(Glyphosate rate)^2	-1.64537	0.0001
Julian date	-0.026041	0.0001
Sin[trans(date)]	-2.10798	0.0001
Site Two		
Survival, percentage		
Intercept	97.77547212	0.0001
Glyphosate rate	-49.9261	0.0014
(Glyphosate rate)^2	13.65379184	0.0512
Julian date	-0.0756306	0.1430
Rate x date interaction	0.0940154	0.1028
Height, centimeters		
Intercept	39.50472151	0.0001
Glyphosate rate	-25.8049	0.0001
(Glyphosate rate)^2	11.12361888	0.0072
Julian date	0.0436936	0.0217
Injury rating		
Intercept	4.37169507	0.0002
Glyphosate rate	2.66833521	0.0001
(Glyphosate rate)^2	-1.0527	0.0001
Julian date	-0.0165471	0.0058
Sine[trans(date)]	-1.37879	0.0064



gure 1. Predicted survival of blolly pine seedlings from April to October 15 (Julian dates 105 288) by rates of glyphosate at te one (top) and site two (bot- m). Abbreviations in equations e provided in the text, above.

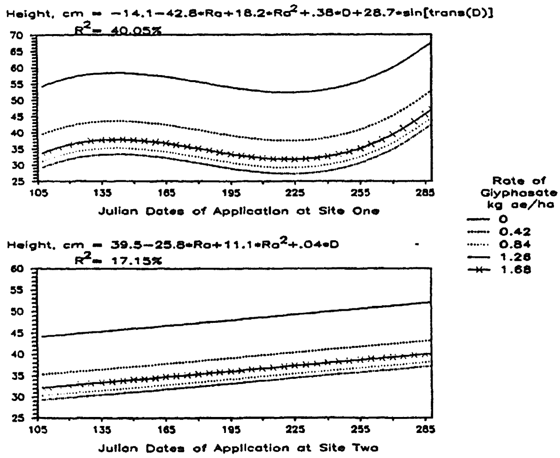
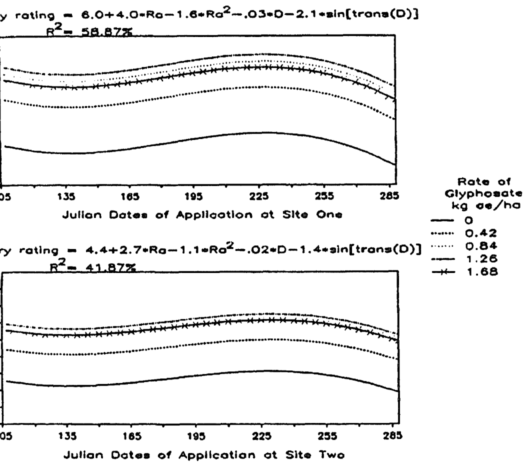


Figure 2. Predicted height of loblolly pine seedlings from April 15 to October 15 (Julian dates 105 to 288) by rates of glyphosate at site one (top) and site two (bottom). Abbreviations in the equations are provided in the text, above.



gure 3. Predicted injury ratings loblolly pine seedlings from Ap- l 15 to October 15 (Julian dates 5 to 288) by rates of glyphosate site one (top) and site two ottom). The 0.84 kg ae/ha res- nse curve is hidden by the 1.68 ae/ha response curve. Abbrevia- ons in the equations are provided the text, above.

Conclusions

The combined adverse effects of glyphosate on loblolly pine survival, height, and vigor suggest that this herbicide should not be broadcast over 1st-year seedlings at 0.42 to 1.68 kg ae/ha, even though these rates corresponded to those recommended on the label. However, glyphosate is not labeled for application until conifer seedlings are established for more than 1 year, when rates as high as 0.84 kg ae/ha are used. Therefore our study may have been too severe a test of this herbicide's capabilities.

Glyphosate was a very effective weed control agent, even at the rate of 0.42 kg ae/ha. Perhaps treatments at rates lower than those on the label would not cause unacceptable injury to seedlings but still provide sufficient weed control. Based on the survival and

height data, we concluded that the overall best date of treatment was October 14, although results were less than satisfactory. This conclusion corresponds to the label directions for the rates of 1.26 and 1.68 kg ae/ha for loblolly pine release.

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PREHARVEST SEEDBED PREPARATION OPTIONS TO ENHANCE LOBLOLLY PINE REGENERATION [1]

Dale Wade, M. Boyd Edwards, and David R. Weise [2]

Abstract. Pine establishment and vegetative competition recovery were observed after combinations of single prescribed burns and herbicide applications just prior to harvest of the pine in a mixed pine-hardwood stand. Four growing seasons after harvest, all treatments resulted in adequate stocking of free-to-grow seedlings. Pine distribution was very uneven on all unburned treatments. Species composition was not affected. Sweetgum was the dominant hardwood species both before and after harvest. Common associates were flowering dogwood, red oaks, black cherry, and winged elm. Herbaceous plants dominated the area for a few years after harvest. Indications are that vines will again dominate the surface vegetation as they did prior to harvest.

Introduction

Privately-owned tracts smaller ɑn 100 ac comprise about 70 perɪt of the South's commercial timːland. Many of these small nonɟustrial private forest (NIPF) ndowners lack the desire, or the pital resources necessary to esblish pine plantations. All too ten these landowners harvest the ghly salable pine component of eir mixed pine-hardwood stands thout regard for future species mposition of the overstory. On e Piedmont Plateau, stands develing after logging cannot be counted on to contain large numbers of gh-value pine without additional treatment. Residual low-value hardwoods capture the site at the expense of the less shade-tolerant pine. An extensive literature base (e.g., Korstian and Coile 1938; Chen et al., 1977; Glover and Dickens 1985) describes the reduction in growth of pine reproduction due to hardwood competition for sunlight, moisture, and nutrients.

We agree with Clason (1989) that implementation of a reforestation plan is the most crucial step in managing a timber stand. Many pre- and postharvest techniques are available for establishing pine. The level of treatment intensity chosen should be dictated by specific onsite conditions, but in practice the cheapest alternative is often chosen. Prescribed fire is the traditional "low tech" treatment. However, if a significant hardwood midstory is present, preharvest dormant-season fires by themselves are generally ineffective because they are not likely to topkill hardwoods over 3-4 inches in diameter. If natural regeneration is to be relied on to reestablish the pine compon-

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Paper presented at Sixth Biennial ɪthern Silvicultural Research Conrence, Memphis, TN, Oct. 30-Nov. 1990.

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ent, another disadvantage of preharvest winter burns is that they give hardwood rootstocks a full growing season to recover before the next seed crop is available. Some combination of fire and mechanical or chemical treatment therefore, is generally recommended. A fire prior to seedfall is attractive because it does not destroy the maturing cone crop, whereas a fire after seedfall or clearcutting destroys the pine seed crop along with any advance regeneration. This necessitates the additional task of seeding or planting the area, making this option more costly to the landowner. The economic benefits of low-cost pine regeneration alternatives have been described by Edwards and Dangerfield (1990).

NIPF landowners often minimize costs by controlling hardwoods themselves. Their options are pretty much limited to prescribed fire, herbicides, or some combination of the two, because they generally do not have access to heavy mechanical equipment such as drum choppers. A major reason small landowners choose preharvest techniques is because they can time the harvest cut to take advantage of the standing cone crop to restock the area. If "enough" vigorous advance reproduction is present, chemical treatment of the broadleaved vegetation has a decided advantage over other choices.

In this paper, we describe pine establishment after low-intensity summer fire, herbicide applied at minimum recommended rates, and combinations of the two. Treatments were imposed before the pine component of a mixed pine-hardwood stand was harvested. Postharvest treatments were compared in a companion study conducted on a nearby site (Bramlett et al., this volume). Early results of these two studies show why landowners who want to promote fiber production are often willing to invest larger sums of money per acre to site prepare and plant.

Methods

The study site was a 90-ac, economically mature, pine-hardwood stand on the Lower Piedmont in Jones County, Georgia, approximately 40 mi north of Macon. No evidence of past fire or previous cultural measures was noted. The pine component was scheduled for harvest after the 1986 seed fall. Specific objectives were to: (1) determine the feasibility of low-intensity summer burns and the ease of fire containment after chemical treatment of the hardwood component; (2) document the recovery of broadleaved vegetation; (3) compare the survival, height, and competitive position of the pine regeneration established after various treatments; and (4) determine whether the order of application of treatment combinations affected objective three.

Eighteen 1.6-ac study plots were installed in a completely randomized design during the spring of 1986 to accommodate three replications of each of six treatments. Stream bottoms and lower slopes where hardwoods predominated were avoided. The following treatments were randomly assigned: (1) burn only (BO); (2) herbicide only (HO); (3) burn and herbicide (BH); (4) herbicide and burn (HB); (5) late-season herbicide (LH); and (6) control (CN). During the summer of 1986 before treatment application, vegetation

less than 4.5 ft tall that originated below groundline on the sample area was tallied along a 300- by 2-ft (600 ft^2) belt transect diagonally bisecting each plot. Vegetation over 4.5 ft tall was tallied along an overlying 300- by 20-ft belt transect encompassing 6,000 ft^2 of each plot.

We found the study area to be floristically diverse. (Individual species are listed in Appendix 1.) Considerable variation was noted in understory amount and stature, and in the ratio of pine to hardwood in the overstory. We attribute much of this variation to a southern pine beetle outbreak in the early '80s. Most of the dead pines were on the ground in 1986.

Herbicide Application

Herbicides were applied during the first week of August or during mid-October. Hardwood stems under 3 inches dbh were stem sprayed with a mixture of 10 percent Garlon 4™, 10 percent Cide-Kick™, and 80 percent diesel fuel using a backpack sprayer. This type of application is commonly referred to as a "thin line" treatment. Hardwoods larger than 3.5 inches dbh were treated with a hypohatchet containing Tordon RTU™.

The amount of Garlon 4 applied ranged from 0.25 to 2.2 and averaged 1.5 pt/ac. The amount of Tordon RTU used ranged from 0.62 to 1.6 and averaged 1.0 pt/ac. Total time to apply both herbicides ranged from 1.25 to 3.4 and averaged 2.5 hr/ac. Use of minimum recommended herbicide concentrations in "thin line" applications, spacing greater than 1 inch between frills in the hypohatchet operation, poor translocation because of severe drought (which lasted into 1989), and/or some stems being missed resulted in incomplete kill of the hardwood midstory and overstory. The fall 1986 survey of herbicide-only, late herbicide, and herbicide-burn plots showed 15 percent of the 648 hardwoods were defoliated while 44 percent showed no signs of herbicide effect. A followup survey in September 1990 showed an average of 14 (5 to 36) midstory hardwoods/ac were still alive on these plots. Over half of these survivors were sweetgum. The next most common survivor was flowering dogwood, which comprised 8 percent of the total.

Prescribed Fires

Dead fuels on the ground were collected on four ¼ milacre subplots in each of the nine treatment plots scheduled for burning, and separated into the following six categories: upper litter layer, duff, twigs less than ¼ inch, twigs ¼ to ½ inch, branches ½ to 1 inch in diameter, and cones. Weight of dead fuels before burning averaged 3.5 and ranged from 2.6 to 4.4 tons/ac (SE 0.14 to 0.55).

The plots were headfired over a 2-day period in September. Our original intent was to burn 4 weeks after herbicide application, but desiccation of the broadleaved foliage did not occur as rapidly as anticipated, so we delayed burning until September 26 and 27, 1986. Linefires were ignited across the lower side of each plot so that they would burn upslope. Three of the plots were eventually ring-fired to ensure burnout before nightfall. Onsite ambient temperature was between 83 and 89°F and relative humidity between 49 and 69 percent during the burns. Within-stand winds were

generally light (0 to 1) and variable. Moisture content of the upper litter layer immediately prior to ignition ranged from 10 to 25 percent. The Keetch-Byram Drought Index stood at 457, suggesting that damage to tree feeder roots should be expected. The fires covered over 95 percent of all but two plots. Rate of spread averaged 1 to 2 ft/min and flame length 0.5 to 1.0 ft. Byram's (frontal) fireline intensity, calculated using consumption data, was very low ranging from 10 to 15 Btu/ft/sec.

Fuels were resampled in the manner described the week after the burns. Consumption of dead fuels ranged from 0.9 to 3.0 tons/ac. In the six fuel categories, consumption ranged between 23 and 61 percent and averaged 55 percent. Two of the nine plots scheduled to receive a fire treatment were dropped from the study because of treatment application problems. One of the plots simply would not burn and the burn on the other was very patchy, covering less than 50 percent of the area. Few overstory pines remained on these two plots after the southern pine beetle outbreak of the early 1980s. As a result, pine litter was insufficient to carry fire under the existing weather conditions.

Hardwood crown damage from both the herbicide and fire treatments was also surveyed the week after the burn. The following week the same herbicide treatment used earlier was applied to the burn-herbicide and late herbicide plots. Logging began immediately after this herbicide application and was completed during November 1986.

Cone Survey

Few maturing cones were noted during the summer of 1986, so we conducted a binocular survey following the methodology suggested by Webb and Hunt (1965). Seed production was estimated to be nonexistent on 9 of the study plots. On the other 9 plots, it ranged from less than 1,000 to 17,500 seeds/ac. Based on this survey, we decided to artificially seed the study area the following spring.

Direct Seeding

All plots were seeded with a mixture of 80 percent treated and stratified and 20 percent untreated and unstratified loblolly pine seed. Seeds were sown at a rate of 1 lb/ac with a cyclone seeder on April 6, 1987. Within plots, seeds were disseminated by first walking the diagonal belt transect midline and then attempting to evenly spread half the remaining seeds on each side of this diagonal.

Response Variables

Advance pine reproduction and germinants were flagged and followed over the next three growing seasons along reestablished 600 ft^2 belt transects that diagonally bisected each plot. Recruitment, survival and height were measured. The likelihood of each seedling eventually becoming part of the overstory was judged using the Virginia Division of Forestry Free To Grow (FTG) classification (Zutter et al., 1984). In this scheme, a 1 denotes a better than 90 percent chance that a seedling or sapling will capture a place in the overstory. A 4 denotes less than a 10 percent chance of reaching the crown canopy. Treatment means were compared by analysis of variance (ANOVA) at the 0.05 level of statistical significance.

Hardwood recovery was monitored for the first 2 years after treatment along the same transects used in the pine surveys. Importance Values (IV) were calculated based on the relative frequency, density, and dominance (basal area) of a species compared to those of all other species using Ohmann (1973) as a guide. Herbaceous plants and shrubs were also measured for two growing seasons after treatment on eight 7.0-ft diameter subplots randomly located along each belt transect.

Results And Discussion

Vegetation Before Treatment

Vegetation Taller Than 4.5 Feet: Twenty-five species groups were tallied in the pretreatment survey of vegetation taller than 4.5 ft. Pine (predominantly loblolly with some shortleaf) basal area ranged from 52 to 81 ft^2 and comprised from 61 to 83 percent of the 92 ft^2 total basal area/ac (Table 1). Sweetgum was the major hardwood midstory species on all but one treatment plot. Its basal area averaged 12 and ranged from 7 to 18 ft^2/ac. Red oaks (primarily water and southern red) and hickory each had a basal area above 9 (13 and 10 ft^2, respectively) on one treatment plot. All other species had basal areas averaging less than 5 ft^2/ac.

Pine occurred in 70 percent of the 400 subplots. Sweetgum and flowering dogwood occurred on 43 percent, red oaks on 20 percent, elm (primarily winged) on 12 percent, and vines (muscadine grape on 40 percent, Japanese honeysuckle on 36 percent, greenbriars on 34 percent) on 74 percent of the subplots.

All other species over 4.5 ft tall occurred on less than 10 percent of the subplots. Number of stems/ac over 4.5 ft tall averaged 2,742 and ranged from 2,422 to 3,121 on the six treatment areas. Pine averaged 852 stems/ac and dominated on all but one treatment plot where it was the second most numerous species behind sweetgum. Flowering dogwood, sweetgum, muscadine grape, honeysuckle, and greenbriars were the most common broadleaved plants. Pine density exceeded 1,000 stems/ac on two treatments and 500 stems/ac on five of the six treatments. Sweetgum numbers exceeded 500/ac on the herbicide-only treatment plots.

Based on the characteristics evaluated, pine was the most important tree species group before treatment. Its importance value (IV) was at least triple that of any other arborescent species group (Table 1). Sweetgum and flowering dogwood were the dominant broadleaved species on most plots. Red oaks, maple, hickory, cherry (primarily black), elm, Japanese honeysuckle, greenbriar, and muscadine grape were also important hardwood midstory species groups.

Vegetation Shorter Than 4.5 Feet: Before treatment an average of 79,798 (69,822 to 97,381) plants/ac less than 4.5 ft tall were present. They were placed in 21 species groups. Vines were the most abundant species group, comprising 64 percent of this total. Herbaceous plants were the second most numerous species group on four of the six treatments averaging 7,780 stems/ac. Flowering dogwood was the most abundant hardwood with 6,857 stems/ac. Stocking of small pines averaged 4,762 stems/ac, but few of these overtopped seedlings would be expected to survive the rigors

Table 1. Descriptors of major plant species groups, 1986 pretreatment survey. Means of 16 plots.

Species	Density (ft) > 4.5	Density (ft) < 4.5	Basal area	Stocking (ft) > 4.5	Stocking (ft) < 4.5	Importance value > 4.5 ft	Subplots dominated by < 4.5 ft
	Stems/ac		ft²/ac	percent			percent
Maple	19	582	<1	03	15	0.033	0
Hickory	29	153	2	06	07	0.074	0
Flowering dogwood	407	6,857	3	43	61	0.410	04
Persimmon	<1	68	<1	<1	03	0.017	0
Herbs	0	7,780			68		04
Sweetgum	327	3,205	12	43	51	0.584	01
Pine	852	4,762	66	70	74	1.918	0
Black cherry	31	1,226	1	07	36	0.066	<01
Red oaks	96	2,355	4	20	55	0.209	0
Winged elm	51	29	2	12	02	0.100	0
Vines	865	51,163	<1	74	99	1.162	91
Mean, all species	2,742	79,798					

of competition and make it into the crown canopy. Vines occurred in virtually all of the 400 subplots, pine in 74 percent, herbs in 68 percent, flowering dogwood in 61 percent, red oaks in 55 percent, and sweetgum in 51 percent of the subplots.

The results of these surveys confirm that vegetation was dense (over 80,000 stems/ac). Pine occurred in 92 percent of all subplots, dominated the overstory, and shared the midstory with sweetgum, flowering dogwood, and red oaks (Table 2), while vines were a major component of both the midstory and understory.

Vegetation after Treatment

Advance Reproduction: Live and dead pine seedlings were tallied and flagged in June of 1987 along the 300- by 2-ft belt transect in each plot. Pines at least 1-year old but less than 4 ft tall were differentiated from new germinants. As expected, surviving advance regeneration was sparse on the seven burned plots, averaging 60 stems/ac. The six unburned plots treated with herbicide contained an average of 230 seedlings, and the controls 218 seedlings/ac (Table 3).

In fall 1989, 642 seedlings/ac were still alive. Most were in the herbicide-only and late herbicide treatment plots. Fifty-six percent of the survivors were in FTG categories 1 and 2. An average of 24 seedlings/ac survived on the three burn treatments, all in FTG category 1.

Pines Established after Treatment: Spring 1987 germinants that survived their first growing season averaged 1,276 stems/ac (Table 4). This number ranged from 315/ac (of which 193 were in FTG category 1) on the

able 2. Density, percent stocking, and importance value of major arborescent species groups, y treatment by year.

	Treatment*							
	BH	BO	CN	HB	HO	LH	Mean	IV
	Stems/ac (Percent stocking)							
retreatment, 1986								
aple	73(04)#	298(12)	660(21)	832(27)	1,554(29)	186(16)	600(14)	
ickory	131(14)	160(12)	190(20)	220(19)	302(13)	85(09)	181(16)	
lowering dogwood	10,509(86)	8,465(78)	2,959(71)	7,764(64)	10,263(89)	3,625(53)	7,264(74)	
ersimmon	36(02)	0	82(04)	194(11)	0	99(03)	69(03)	
veetgum	3,351(70)	1,150(48)	3,269(91)	3,727(79)	5,946(85)	3,744(71)	3,532(74)	
ine	5,503(94)	5,380(84)	5,456(94)	5,973(99)	5,726(95)	5,646(85)	5,614(92)	
lack cherry	1,165(54)	1,006(42)	1,097(41)	1,225(48)	1,384(39)	1,067(37)	1,157(44)	
ed oaks	3,460(76)	2,842(86)	2,103(65)	2,328(49)	2,393(60)	1,518(53)	2,452(65)	
inged elm	33(18)	80(28)	121(27)	17(09)	227(37)	05(11)	80(22)	
ost treatment, Fall 1987								
aple	36(17)	0	994(75)	121(33)	278(56)	218(22)	274(34)	0.084
ickory	109(67)	563(67)	122(50)	109(33)	133(33)	97(56)	189(51)	0.164
lowering dogwood	762(100)	1,234(83)	1,102(88)	666(89)	1,742(100)	1,101(89)	1,101(92)	0.505
ersimmon	254(100)	200(83)	54(25)	109(67)	48(33)	242(67)	151(62)	0.106
veetgum	3,775(100)	3,158(100)	3,062(100)	2,735(100)	1,718(89)	1,912(89)	2,728(96)	0.681
ine	526(100)	599(100)	884(75)	411(67)	569(67)	363(78)	559(81)	0.353
lack cherry	889(100)	653(83)	749(100)	242(78)	762(89)	750(78)	674(88)	0.314
ed oaks	1,506(100)	1,307(100)	1,578(100)	726(89)	2,009(100)	1,016(100)	1,357(98)	0.377
inged elm	436(83)	436(67)	286(62)	60(33)	714(100)	121(56)	342(67)	0.122
ost treatment, Fall 1988								
aple	0	0	1,225(62)	73(11)	254(56)	194(33)	291(27)	0.082
ickory	54(33)	272(67)	150(38)	73(44)	24(22)	12(11)	98(36)	0.139
lowering dogwood	399(100)	1,125(83)	708(88)	762(89)	1,222(100)	895(89)	852(91)	0.283
ersimmon	0	36(33)	54(25)	36(33)	12(11)	24(22)	27(21)	0.032
veetgum	2,269(100)	1,996(100)	2,627(100)	2,130(100)	1,718(100)	1,512(100)	2,042(100)	0.953
ine	690(100)	1,143(100)	925(100)	1,234(100)	1,186(100)	690(100)	978(100)	0.574
lack cherry	363(100)	345(83)	299(75)	97(56)	532(100)	593(78)	372(82)	0.169
ed oaks	1,125(100)	926(100)	1,020(100)	726(89)	1,621(100)	786(89)	1,034(96)	0.324
inged elm	254(83)	381(50)	231(50)	36(33)	411(79)	73(78)	231(62)	0.155

Treatment abbreviations explained in the methods section.

Number of stems is first number with percent stocking in parenthesis. Stocking based on twenty-five 24 and 240 ft^2 subplots/plot in 1986, and on three 400-ft^2 subplots per plot in 1987 and 1988.

ate-herbicide plots to 1,765/ac (532 were in FTG class 1) on the herbi-de-burn plots. A year later, survival of these seedlings ranged from 32 ercent on the late-herbicide plots to 85 percent on the herbicide-burn ots (Table 5). Duncans multiple range test with arcsine-transformed sur-ival data indicated that survival was significantly better on herbicide-urn plots than survival on the herbicide-only and late-herbicide plots.

Table 3. Advance pine regeneration on a per-acre basis by free to grow class and treatment by year.

Treatment*	FTG class 1	2	3	4	Total
	-- (Seedlings/ac) --				
Fall 1987					
BH	0	36	0	36	72
BO	36	0	36	36	108
CN	82	82	27	27	218
HB					0
HO	24	0	24	0	48
LH	218	145	48	0	411
Total	360	263	135	99	858
Fall 1988					
BH					0
BO	36	36	0	0	72
CN	0	82	27	0	109
HB					0
HO	0	24	24	0	48
LH	97	97	145	0	339
Total	133	239	196	0	568
Fall 1989					
BH					0
BO	72	0	0	0	72
CN	54	0	27	0	81
HB					0
HO	97	48	48	97	290#
LH	54	36	0	109	199
Total	277	84	75	206	642

* Treatment abbreviations explained in the methods section.

\# Apparent increase in number of seedlings/ac is due to change in blow-up factor because of loss of one treatment plot between 1988 and 1989 surveys.

In the 1989-1990 dormant season survey, dead or missing pines were not tallied and new recruits were recorded as existing pines, so percent survival could not be determined. New germinants continued to show up on all but the late-herbicide plots. These recruits occurred mainly along the uncut forest edge. By fall 1989, all postharvest seedlings on the late-herbicide plots had died (Table 4). Excluding that treatment, the number of seedlings judged to have a good chance of becoming overstory canopy trees (FTG classes 1 and 2) ranged from 146/ac on the control plots to 583/ac on the herbicide-burn plots. Results after 3 years show that all treatments-- except the late-herbicide and control-- produced over 425 free-to-grow pines/ac. Combining new recruit and advance regeneration data indicates a sufficient number of pine seedlings were produced on all treatments to assure that this species will again dominate the overstory of the developing stand.

Although no pine seedlings were tallied on the late-herbicide plot transects in 1989, numerous seedlings were observed elsewhere on these plots. In September 1990, we therefore evaluated pine regeneration on three 1/100-ac subplots established along the opposing diagonal of every plot (Table 4). Pine recruitment was still taking place on all treatments. The maximum number of first-year germinants tallied was 211/ac on the herbicide-burn treatment plots. A few pines judged to have been established prior to treatment were found on herbicide-only and control plots. Excluding both advance reproduction and new germinants, this supplemental survey showed that pines likely to comprise the developing overstory (FTG classes 1 and 2) were most numerous on the late-herbicide treatment plots (950), and least numerous on the herbicide-only treatment plots (233).

Table 4. Mean pine density and height by treatment and free to grow class.

Treatment *	FTG class 1		FTG class 2		FTG class 3		FTG class 4		Total density
	Density	Height	Density	Height	Density	Height	Density	Height	
	stems/ac	ft	stems/ac	ft	stems/ac	ft	stems/ac	ft	stems/ac
Fall 1987									
BH	363	0.35	544	0.40	436	0.37	0		1,343
BO	690	0.45	472	0.38	326	0.24	218	0.20	1,706
CN	218	0.55	424	0.18	218	0.32	145	0.21	1,005
HB	532	0.34	798	0.20	411	0.16	24	0.10	1,765
HO	49	0.27	823	0.38	532	0.41	121	0.30	1,525
LH	193	0.32	73	0.08	49	0.27	0		315
Mean		0.38		0.27		0.30		0.20	1,276
Fall 1988									
BH	581	0.74	363	0.58	36	0.55	36	0.35	1,016
BO	544	0.79	254	0.57	97	0.21	218	0.35	1,113
CN	145	0.62	351	0.72	314	0.41	121	0.16	931
HB	726	0.58	774	0.67	24	0.10	49	0.27	1,573
HO	97	0.72	436	0.98	363	0.52	169	0.65	1,065
LH	97	0.70	49	0.40	24	0.16	24	0.20	194
Mean		0.69		0.65		0.32		0.33	982
Fall 1989									
BH	472		73		36		254		835
BO	326		109		109		472		1,016
CN	85		61		36		617		799
HB	559		24		243		678		1,500
HO	290		254		218		617		1,380
LH	0		0		0		0		0
Mean									922
Fall 1990 #									
BH	450		383		317		50		1,200
BO	283		433		567		150		1,433
CN	222		289		311		233		1,055
HB	267		600		1,033		600		2,500
HO	33		200		284		400		916
LH	400		550		367		300		1,616
Mean									1,453

* Treatment abbreviations explained in the methods section.

Supplemental survey based on three 1/100-ac subplots per plots. Numbers exclude first year germinants.

We attribute the large differences in seedling numbers between the two surveys to seedling distribution patterns. The late-herbicide, herbicide-only and control treatments do not remove litter and duff. These layers often dry out before the rootlets of germinating pine seeds can penetrate

Table 5. **Survival of posthavest pine regeneration by treatment for 1987 and 1988.**

Year	Treatment BH	BO	CN	HB	HO	LH
1987	90	88	88	86	80	72
1988	65ab*	56ab	65ab	85a	44b	32b

Dependent variable: arcsine transformation of survival

R^2	C.V.	Root MSE	Mean	Pr > F
0.624649	22.06699	11.25838	51.019	0.0340

* Values with different letters within the same year are significantly different at the 0.05 level of probability.

through to the underlying mineral soil. Both 1987 and 1988 were drought years in middle Georgia. Seedling establishment on unburned plots was therefore confined to areas scarified by logging equipment which resulted in very uneven distribution. No patches of reproduction happened to occur on the belt transects in the late-herbicide plots.

Based on the results of both surveys, we conclude that adequate free-to-grow seedlings are present to ensure the new stands on all treatment plots will contain a significant pine component. The distribution of these seedlings, however, is disappointingly uneven on control, herbicide-only and late-herbicide treatment plots.

Seedling heights at the end of the first and second seasons after treatment did not differ significantly by treatment (Table 4). Pine recruitment continued throughout the measurement period and each seedling was flagged but not individually tagged. Thus plots with many new recruits had many small trees. These trees were not separated in the field from those a year older, so growth of older seedlings was masked by new recruits. Significant height differences were found among FTG classes in 1988, and one would expect seedlings with little competition to be taller than those being subjected to severe competition.

Herbaceous And Vine Response: In the fall of 1987, herbaceous vegetation covered from 32 to 40 percent of the ground surface (Table 6). In the fall of 1988, herbaceous cover of the ground surface ranged from 33 percent on the controls to 58 percent on the herbicde-burn plots. Vines covered an average of 6 percent of the subplots in 1987 and 11 percent in 1988. We expect the coverage of vines to increase at the expense of the herbaceous component over the next few years.

Twenty-two species groups were tallied on the study plots during the fall of 1987. Nutsedges were the most common herbaceous plant, occurring

le 6. Percent of 1/100 ac subplots stocked with indicator species and the rage subplot coverage associated with six preharvest seedbed preparation atments on the Georgia Piedmont.

		Treatments*						
		BH	BO	CN	HB	HO	LH	Mean
		(percent)						
estems								
Yr 1	Stocking	19	31	45	29	50	33	34
	Cover	02	02	04	01	08	02	03
Yr 2	Stocking	19	38	40	54	46	42	40
	Cover	01	01	03	02	10	02	03
sedges								
Yr 1	Stocking	75	81	55	96	58	58	70
	Cover	11	10	06	10	02	08	08
Yr 2	Stocking	12	0	0	04	0	0	3
	Cover	01	0	0	01	0	0	< 01
megrass								
Yr 1	Stocking	50	50	50	42	62	58	52
	Cover	05	05	05	04	09	07	06
YR 2	Stocking	50	25	30	33	58	58	42
	Cover	04	03	02	03	07	05	04
te eupatorium								
Yr 1	Stocking	81	44	59	92	67	58	67
	Cover	13	04	08	13	09	10	10
Yr 2	Stocking	31	12	0	12	04	12	12
	Cover	02	01	0	03	<01	04	01
anese honeysuckle								
Yr 1	Stocking	31	38	36	21	33	17	29
	Cover	01	02	02	01	02	01	02
Yr 2	Stocking	50	38	70	21	67	54	50
	Cover	03	03	06	02	04	04	04
icums								
Yr 1	Stocking	0	0	0	0	0	0	0
	Cover	0	0	0	0	0	0	0
Yr 2	Stocking	94	56	85	88	83	75	80
	Cover	29	15	19	30	12	22	21
cadine								
Yr 1	Stocking	31	62	55	29	50	50	46
	Cover	03	05	05	01	04	07	04
Yr 2	Stocking	31	38	35	21	42	46	36
	Cover	07	05	13	02	07	06	07
ds and grasses								
Total cover								
Yr 1		40	34	32	40	36	40	37
Yr 2		51	34	33	58	46	55	46
es								
Total cover								
Yr 1		05	07	07	03	06	08	06
Yr 2		11	09	20	04	12	11	11

reatment abbreviations explained in the methods section.

on 70 percent of all subplots followed by white eupatorium (fireweed) or
percent of all subplots (Table 6). Plumegrass and muscadine grape occur
on more than 50 percent of the subplots in two treatments. Five spec
each comprised more than 10 percent of the total herbaceous cover the fi
post-treatment year: white eupatorium (22 percent); nutsedges (19 percen
plumegrass (14 percent); lespedeza (12 percent); and muscadine grape
percent). On a treatment basis, bluestems (21 percent on herbicide-o
plots) and paspalum grasses (10 percent on herbicide-burn plots) are ad
to the above list.

Twenty-three herbaceous species and species groups were recorded dur
the fall 1988 survey. Nutsedges were only observed on 3 percent of
subplots and fireweed on 11 percent (Table 6). Panicums (including ca
grass) were found on 80 percent of all subplots. Honeysuckle occurred
50 percent of the study subplots. Plumegrass occurred on over half of
plots in the herbicide-only and late-herbicide treatments and bluestems
over half the herbicide-burn treatment plots. The second year after tre
ment, panicums (37 percent) and grape (12 percent) each comprised more t
10 percent of the total herbaceous cover. On a treatment basis, goo
grass, comprised 15 percent of the hebaceous cover on the burn-herbic
plots and 13 percent on the late-herbicide plots; honeysuckle 12 percent
the controls; bluestems 17 percent, plumegrass 12 percent and lespedeza
percent on the herbicide-only plots.

Non-arborescent Hardwoods: Only four species of shrubs were not
winged sumac, poison oak, blueberry, and hawthorn. A total of 162 pla
were tallied the first year after treatment; 96 of them on the herbici
burn treatment plots. One hundred twenty-nine of these shrubs were win
sumac, the only species that occurred on more than half the subplots wit
a treatment. It occurred on 62.5 percent of the subplots on the herbici
only treatment but still shaded less than 2 percent of the ground.

The shrub component became even less important the following year.
total of 108 plants were recorded; 59 of them were on the herbicide-b
treatment plots. Forty-eight of the stems were blueberries and 47 w
winged sumac.

Arborescent Hardwoods And Pine: Twenty-one species groups were
corded in the fall survey one year after logging. Although no spec
occurred in every subplot, flowering dogwood, sweetgum, and red oaks w
found in more than 90 percent of all subplots (Table 2). Pine and che
occurred in more than 80 percent of the subplots and hickory, persimm
and elm occurred in more than 50 percent of the subplots. Stem dens
averaged 8,000/ac. Thirty-four percent (2,700) of these stems were swe
gum. Flowering dogwood and red oaks also averaged more than 1,000 ste
ac. Eastern redbud exceeded 1,000 stems/ac 1 year after the herbicide-o
treatment. Maple, hickory, pine, black cherry, and elm exceeded 500 ste
ac 1 year after at least one of the treatments.

In the fall, 2 years after treatment, 18 species groups were fou
Pine and sweetgum occurred on all study subplots (Table 2). Flowering d
wood and red oaks appeared on more than 90 percent, cherry on more than
percent, and elm on more than 50 percent of all subplots. Average num
of woody stems/ac of the three major species groups each decreased

bout 20 percent resulting in a total of 6,400 stems/ac for all species. ecreases of this magnitude between first and second year hardwood seed- ings have been noted in other studies and are thought to simply reflect atural selection processes. Sweetgum continued to dominate the vegeta- ion, now comprising 38 percent of the total number of stems. Two years fter at least one of the treatments, maple, flowering dogwood, pine, and ed oak numbers all exceeded 1,000/ac. Eastern redbud and black cherry umbers exceeded 500 stems/ac after at least one of the treatments. There s little doubt that sweetgum will dominate the hardwood component of the eveloping stand with flowering dogwood, red oaks, cherry, and elm as ommon associates.

The temporary increase in succulent sprouts should attract a wide range f wildlife such as quail, turkey, and deer. Many of the most common plant pecies groups recorded on the study transects are considered to be of rimary wildlife value in middle Georgia (Wade et al., 1989). These pecies include black cherry, herbs, honeysuckle, red oaks, greenbriars, nd muscadine grape.

Summary And Conclusions

A low-intensity late-summer underburn 2 months after "thin line" herbi- ide treatment was safe and easy to conduct. Establishment of pine seed- ings was best on the herbicide-burn treatment but all six treatments pro- ided more than enough FTG class 1 and 2 seedlings to eventually dominate he overstory of the developing stand. The distribution of these seedlings as very uneven on control, herbicide-only, and especially late-herbicide lots.

Seedbeds remained receptive to pine establishment for several years af- er treatment. The failure to recognize the need to specifically identify ew recruits prevented meaningful comparison of any differences in pine eedling height between treatments.

The herbicide treatments used, preserved advance pine regeneration. efore considering the use of fire, advance reproduction should be evalu- ted including an assessment of the number of stems likely to capture a lace in the overstory of the next stand. Variation in pine development ithin treatments shows the value of site-specific preparation prescrip- ions over a single generalized prescription for the whole area (see oorhead and Dangerfield, this volume).

The hardwood component was drastically reduced by all treatments but is apidly recovering from surviving rootstocks. It appears sweetgum will ominate the hardwood component of the developing stand with flowering dog- ood, red oaks, elm, and cherry as common associates. Herbaceous species ominated all treatment plots soon after harvest. The abundance of indi- idual species was treatment specific. Vines were a major component of the urface vegetation prior to harvest and should become so again, especially t the expense of the herbaceous plants, as succession continues. Results emonstrated that: (1) a single preharvest low-intensity summer prescribed

fire, by itself or in conjunction with selective herbicide treatment of residual hardwoods is a practical seedbed preparation technique to reestablish southern pine on lower Piedmont mixed pine-hardwood sites; (2) combining the selective use of herbicides with fire can further increase the probability that pine will dominate the canopy of the emerging forest stand; (3) herbicide treatments do not expose mineral soil seedbeds and therefore may result in uneven distribution of pine reproduction; and (4) wildlife values are enhanced, at least temporarily, by these treatments.

Acknowledgments

Authors thank the Georgia Forestry Commission for financial support of this study, and Keith Wilson for providing the study area.

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Appendix 1. List of plant species found on the study plots

Woody Plants

American holly	*Ilex opaca*	Japanese honeysuckle	*Lonicera japonica*
American hornbeam	*Carpinus caroliniana*	Loblolly pine	*Pinus taeda*
Ash	*Fraxinus* spp.	Muscadine grape	*Vitus rotundifolia*
Black cherry	*Prunus serotina*	Persimmon	*Diospyros virginiana*
Black tupelo	*Nyssa sylvatica*	Poison oak	*Toxicodendron toxicarium*
Blueberry	*Vaccinium* spp.	Red maple	*Acer rubrum*
Eastern hophornbeam	*Ostrya virginiana*	Red mulberry	*Morus rubra*
Eastern redbud	*Cercis canadensis*	Sassafras	*Sassafras albidum*
Eastern redcedar	*Juniperus virginiana*	Shortleaf pine	*Pinus echinata*
Florida maple	*Acer barbatum*	Southern red oak	*Quercus falcata*
Flowering dogwood	*Cornus florida*	Sweetgum	*Liquidambar styraciflua*
Greenbriars	*Smilax* spp.	Water oak	*Quercus nigra*
Hackberry	*Celtis* spp.	White oak	*Quercus alba*
Hawthorn	*Crataegus* spp.	Winged elm	*Ulmus alata*
Hickory	*Carya* spp.	Winged sumac	*Rhus copillina*
Honeylocust	*Gleditsia triacanthos*	Yellow-poplar	*Liriodendron tulipifera*

Herbaceous Species

American burnweed (fireweed)	*Erechites* spp.	Panicums (inc. low panicums)	*Panicum* spp.
Aster	*Aster* spp.	Partridgepea	*Cassia* spp.
Blackberry	*Rubus* spp.	Paspalum grasses	*Paspalum* spp.
Bluestems (broomsedge)	*Andropogon*	Plumegrass	*Erianthus* spp.
Dogfennel	*Eupatorium* spp.	Purple love grass	*Eragrostis* spp.
Elephant's foot	*Elephantopus* spp.	Purpletop grass (grease grass)	*Tridens* spp.
Goldenrod	*Solidago* spp.	Rabbit tobacco	*Gnaphalium* spp.
Goosegrass	*Eleusine indica*	St. Johnswort	*Hypericum* spp.
Lespedeza	*Lespedeza* spp.	Spike grass	*Uniola* spp.
Nutsedges	*Cyperus* spp.	Tickclover	*Desmodium* spp.
White eupatorium (fireweed)	*Eupatorium album*		

NATURAL HARDWOOD REGENERATION 6 YEARS AFTER CLEARCUTTING AS INFLUENCED BY HERBICIDE INJECTION AND SCALPING [1]

George Hopper, Allan Houston, and Edward Buckner [2]

Abstract. Forty-five acres of mature upland hardwood timber on the Ames Plantation in west Tennessee were clearcut during summer 1983. Timber volumes were high (10 MBF/ac, Doyle) with 92 percent of overstory comprised of southern red oak (Quercus falcata Michx. var. falcata). Advance regeneration over the entire tract was low or nonexistent. Nine contiguous 1-ac blocks were established within the silviculture clearcut and two treatments randomly assigned: (1) post harvest injection with Tordon 101™ of dogwood (Cornus florida L.), red maple (Acer rubrum L.) and miscellaneous hickories (Carya spp.); and (2) same as treatment one with scalping of the site (all litter, but little soil removed) with a bulldozer. The composition and height of regeneration was measured following the first and sixth growing seasons. Hardwood regeneration over the entire area six growing seasons after harvest averaged 2,248 stems/ac, with approximately 10 percent oak species. Regeneration was significantly reduced with increased treatment intensity with 2,686 stems/ac for control, 2,287 stems/ac for injection plots and 1,771 stems/ac for scalping plots. Scalping had no effect on the number of oak, ash (Fraxinus spp.), and yellow-poplar (Liriodendron spp.). Evidence is presented suggesting that the treatments influenced the effectiveness of birds, wind, and gravity as vectors for distributing tree seed.

Introduction

In contrast to more intensively managed conifer stands where regeneration is usually accomplished by planting nursery-grown seedlings, management systems for hardwoods generally rely on natural regeneration. A common problem following harvests in hardwoods is that harvested stands with a high percentage of desirable lumber species often regenerate to stands largely stocked with undesirable lumber species.

Clearcutting as a silvicultural practice has been under close scrutiny for several years. Many foresters and natural resource professionals, although convinced that clearcutting may be good for regeneration, recognize that it has limitations. Clearcutting has not generally been successful at regenerating oaks on good oak sites in the absence of advanced oak reproduction. This lack of oak reproduction has led many forest scientists to question the use of clearcutting, especially when regenerating oak is of primary importance. It is now

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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dely accepted that hardwood regeneration, especially that of oaks, is mmonly of coppice origin. However, large-diameter trees generally do not rout from stumps (Allen 1990). Developing cultural practices that encour-e root sprouting from the large root systems of harvested oaks while re-cing the competition from undesirable species might justify the use of ch an economically attractive regeneration method. This is especially ue where advance regeneration is below optimum levels.

While increased representation of pioneer species is expected where rge openings are created, compositional shifts often do not follow this ttern, especially where fast-growing coppice dominates regeneration. En-uraging coppice regeneration from the root systems of desirable lumber ecies while discouraging coppice from undesirable lumber species might ovide an attractive alternative. Furthermore, exposure of mineral soil lightly scalped clearcuts may allow for pioneer and light seeded species regenerate. The purpose of this paper is to report the effects of in-cting undesirables residuals and scalping as follow-up treatments after earcutting a mature upland southern red oak (Quercus falcata Michx.) and in west Tennessee.

Methods

A 45-ac, 90- to 100-year-old red oak stand on Ames Plantation in uthwest Tennessee was clearcut in the summer of 1983. The area was ined on three sides by hardwood forest. Site index for the harvested and was 90 for southern red oak (Q. falcata Michx. var., falcata; base e 50 years). The tract averaged 7,850 bd ft/ac (Doyle) and was 93 percent d oak, mainly southern red, with lesser volumes of black oak (Q. velutina m.), and northern red (Q. rubra L.). The other species harvested from e stand were green ash (Fraxinus americana L.), black cherry (Prunus ser-ina Ehrh), hickories (Carya spp.), black gum (Nyssa sylvatica L.) and eet gum (Liquidambar styraciflua L.). The advanced reproduction was pri-rily flowering dogwood (Cornus florida L.), red maple (Acer rubrum L.), d miscellaneous hickories. Although no quantitative measurements were ken, there was little advanced oak reproduction.

Following commercial clearcutting of all merchantable timber, nine uare, 1-ac plots were located near the center of the harvested area. ot corners were marked with stakes. Three replications of two treatments re randomly assigned to the nine plots. Treatments, including the con-ol, were: (1) All residual stems greater than 1-inch diameter were cut to complish the silvicultural clearcut (control); (2) All dogwood, hickory, d red maple greater than 1 inch in height were injected with Tordon 101™ kill their root systems to prevent sprouting (injection); (3) Same as eatment 2 except that the area was scalped using a standard bulldozer ade to push all logging slash and litter off the plot (scalping). All her species greater than 1 inch diameter were cut without chemical treat-nt to permit their root stocks to provide desirable coppice regeneration. me topsoil was removed in the scalping operation. This treatment was done encourage root sprouting of the desirable species that were not chemic-ly deadened and encourage seeding from wind and birds.

All treatments were in place by October 1, 1983. In order to follow fate of individual trees and compare species change in growth and survival, 27 milac plots were established as permanent plots in each treatment. Twenty-five cells located in five rows and five columns were established in each milac plot to locate individual trees. Baseline measurements were made at the end of the first and sixth full growing seasons. Data collection included; height and species of dominant stem in each cell, number of stems for each species, and the percentage of the ground covered by honeysuckle vine [Lonicera japonica (L. Thunberg)].

In addition, at the end of the sixth growing season, three 10 x 142 ft strip transects were placed randomly to tally all regeneration on 9.8 percent of each block. All statistical analyses were performed with GLM procedures and mean separation accomplished with Duncan's Multiple Range test (SAS 1985).

Results And Discussion

With the increasing treatment intensity there was a parallel reduction in total number of stems at year 6 (Table 1). At year 6, across all treatments the developing stand averaged 2,247 stems/ac. Control plots averaged 2,685 stems/ac which is similar to the hardwood regeneration reported by other researchers following clearcutting (Walters 1989, Martin and Hornbeck 1990).

Scalped treatments had the lowest stem count, 1,770 stems/ac. Scalping removed most of the seed in place. Although scalping appeared to reduce the total stem count, overall stocking levels in these plots were still good compared to the control plots. Moreover, the percentage of the number of desirable species stems (oak, ash, and yellow poplar) to the total number of stems in the scalped treatments (26.7 percent) was better than the percentage of desirables in the control plots (19.7 percent). The reduced numbers of regenerants in the scalped plots, may benefit the desirable species since there will be less competition in future years.

Although there were fewer stems of dogwood, red maple and hickory in the injection treatments, the numbers of these species were not different across all treatments (Table 1). There was a significant increase in the amount of honeysuckle competition on the injection plots with 41.1 percent groundcover at year 1, compared with the control plots (15.2 percent) and the scalping plots (12.9 percent) (Table 2). The higher groundcover persisted through year 6. However, there was no significant difference in the change in groundcover over the 6 years compared among treatments (Table 2). The honeysuckle probably was greatest in the injection plots because partially deadened overstory released the vines. In the scalping plots, vine competition was removed by the bulldozer. Moreover, vine competition likely retarded growth in injection plots and may influence the compositional and successional changes of these plots in the future (Table 3).

reatments included a control (silvicultural clearcut), injection (same s control with injection of dogwood, red maple, and hickory), and calping (same as injection with scalping of ground lightly).

Species	Control	Inject.	Scalp.	Overall $\bar{X}$
	(stems/ac)			
uercus spp.*	232.1	204.5	207.6	214.7
raxinus pennsylvanica	194.3	184.0	122.7	167.0
iriodendron tulipifera	105.3	245.4	143.1	164.6
runus serotina	187.1	115.5	112.4	138.3
iquadambar styraciflua	10.2	48.0	23.5	27.2
cer rubrum	273.0	129.8	40.9	147.9
iospyros virginiana	119.6	119.6	44.0	94.4
assafras albidum	109.4	48.0	13.3	56.9
ercis canadensis	10.2	84.9	13.3	56.9
lmus alata	347.6	316.9	136.0	266.8
yssa sylvatica	143.1	65.4	224.9	144.4
ornus florida	313.9	258.7	242.3	271.6
arya spp.**	514.3	350.1	398.8	421.1
inus taeda	10.2	0.0	51.1	20.4
cer negundo	115.5	116.9	10.2	80.8
Total	2685.8	2287.7	1770.8	2247.8

Most of the red oaks were *Q. velutina* (black oak), *Q. rubra* (northern red oak), and *Q. falcata*, (southern red oak). There were no white oaks found in the study area.

* Hickories were *C. glabra* (pignut hickory) and *C. ovata* (shagbark hickory).

able 2. The percentage of groundcover in honeysuckle by treatment for ears 1 and 6.

	Control	Injection	Scalping
	(percent vine cover)		
ear 1	15.2 b[1]	41.1 a	12.9 b
ear 6	27.9 b	48.9 a	18.0 b
ear 1 to year 6 change	12.7 a	7.8 a	5.1 a

Means with same letter in a row are not significantly different at P = 0.05 as tested by Duncans Multiple Range Test for Significance; df = 257.

Table 3. Percent change in the number of trees, total height growth, and percent change in height growth over 6 years, 6 years after harvesting a mature red oak stand in west Tennessee for three clearcut harvest treatments.

Variation	Control	Injection	Scalping
Percent change in number of trees	-1.7 b[1]	+6.7 a	+5.1 a
Height growth (cm)	226.0 a	187.4 b	156.4 b
Percent change in height growth	75.8 a	69.5 a	70.6 a

[1] Means followed by same letter in row are not significantly diffeent at P = 0.05 as tested by Duncans Multiple Range Test for significance; df = 257.

Over the 6-year period, the number of trees on permanent plots decreased in only the control plots (-1.7 percent). Whereas on the injection and scalping plots, the number of trees increased 6.7 and 5.1 percent, respectively (Table 3). Similar delayed reproduction increases have been reported in scarified clearcuts in Canada and Pennsylvania for up to 3 years (Martin and Hornbeck 1989).

Despite greater stocking, height growth at year 6 was greatest in the control plots (Table 3). A factor affecting this comparative growth performance is that scalping and honeysuckle competition may have stunted the early growth of seedlings on the injection and scalped plots. Scalping may have reduced the organic layer to the detriment of the seedling growth. Honeysuckle competition in the injection plots probably held the growth of seedlings back in those plots.

However, the percent change in height growth from year 1 to year 6 reflects no difference among treatments (Table 3). This statistic indicates that although the newly established regenerants were initially smaller in the injection and scalping plots, the rate of growth was not significantly less than on control plots. Thus, if the tree competition is less and the growth rate the same, then perhaps the more intensely treated plots will catch up in growth in future years. At the end of the sixth growing season, the height growth increase over the first 6 years are 75.8, 69.5, and 70.6 percent for the control, injection, and scalping plots, respectively (Table 3).

Regeneration by species seemed to be associated with seed dispersal mechanisms that were in turn influenced by the increasing intensity of treatment. Table 4 shows the species listed according to dispersal methods: bird, gravity, or wind.

In general, plots with high ground cover at year 1 tended to regenerate to species with seed dispersal largely dependant upon birds (Table 5). Across all treatments, species with seed dispersed by birds were found on

ble 4. Species grouped in association with their seed dispersal mec-
nisms.

Bird	Wind	Gravity
ssafras albidum	Acer negundo	Quercus spp.
unus serotina	Fraxinus pennsylvania	Carya spp.
ospyros virginiana	Liriodendron tulipifera	
rnus florida	Pinus taeda	
ssa sylvatica	Acer rubrum	
rcis canadensis	Ulmus alata	
	Liquadambar styraciflua	

ble 5. Percent change over 6 years in stocking and height growth ac-
rding to seed dispersal mechanisms (bird, wind, or gravity) for each
rvest treatment.

Treatment/ mechanism	Stocking change	Height growth
	--- percent ---	---- cm ----
Control		
Bird	-4.5	220.7
Wind	3.3	246.2
Gravity	-4.3	212.0
Injection		
Bird	8.0	209.7
Wind	5.6	181.2
Gravity	5.4	148.0
Scalping		
Bird	1.0	116.0
Wind	4.9	178.4
Gravity	9.2	158.8
erall totals		
Bird	2.6	186.8
Wind	4.7	200.7
Gravity	2.9	182.7

plots with an average of 32 percent ground coverage; and was significantly higher than plots regenerated to wind dispersed species (18 percent) and gravity dispersed species (19 percent). This fact probably reflects increased foraging and perching of birds in the vine cover during the fall 1983 and early winter 1984. In the control plots during the first 6 years, wind seeded species continued to increase in numbers of regenerants per acre at 3.3 percent, but the numbers of regenerants decreased in the bird and gravity seeded species at -4.5 and -4.3 percent, respectively (Table 5). Wind dispersed species may have the ability to invade clearcuts more aggressively than bird or gravity dispersed species. Also, some avian species may be reluctant to access the interior portion of large clearcuts (Thompson and Fritzell 1990).

There seemed to be more bird dispersed species in the injection plots. Between years 1 and 6 there was an 8.0 percent increase in bird dispersal species compared with 5.6 and 5.4 percent increase in wind and gravity species, respectively (Table 5). This increased number may reflect the increased activity of birds in the heavy vine covered injection plots. Likewise, the scalping plots that had mineral soil exposed and less vine competition showed increased regeneration of the species dispersed by wind and gravity (Table 5). Wind dispersed species increased 4.7 percent and gravity dispersed tree species increased 9.2 percent in the scapled plots. The increase in gravity dispersed species probably reflects delayed and continued sprouting of oak and hickory seedlings between year 1 and year 6. Also, less honeysuckle and lower stocking in the scapled plots may have contributed to the continued seeding of the gravity dispersed species.

Height growth was somewhat consistent among all species, regardless of the dispersal system (Table 5). The wind dispersed species tended to be taller at age 6, reflecting the pioneer habit of most of these lighter seeded species.

Conclusions

The two treatments appeared to have little effect on oak regeneration with only slightly fewer stems per acre than the control plots. However, the decreased regeneration of undesirables in these plots was notable, especially the very few red maples present in the scalped plots. These results suggest that the composition of regeneration in the treated plots may shift toward more desirable species (oak, ash, and yellow-poplar). Further, due to lower stocking, desirable species may be more likely to comprise the dominants in the future stand.

Height growth was somewhat better in the control plots. This was probably because of the top soil damage on the scalped plots and the honeysuckle competition on injection plots. However, close analysis shows that height growth rates over the 6-year period were not different across all treatments. Although scalping reduced the growth and total regeneration, these losses were not significant. In fact, lower density in the scalped plots may provide less competition and greater future growth. It was also

letermined that a heavy initial vine component may tend to regenerate to :ree species dispersed by birds.

Regeneration is prolific in a clearcut from a variety of seed and sprout origins. Dispersal of seed and the establishment of seedlings de- ends on ground conditions throughout at least the first 6 years of growth. Successional changes in composition and growth of the established vegeta- :ion requires long-term study and detailed analysis. Ecologically, the lisruption of a clearcut is severe, and understanding the consequential ef- :ects is very difficult. However, we found that operations such as scalp- .ng and injection of herbicides, which are more intense than clearcutting ılone, do not prevent regeneration of hardwood tree species. Predicting :he natural regeneration outcome in a clearcut where advance regeneration .s below critical levels is uncertain and long-term consequences need :uther study.

Acknowledgments

'his study was funded by Hobart Ames Foundation and McIntyre-Stennis Re- search. The authors acknowledge Robert Smith for his review of the ıanuscript.

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THE VALUE OF SITE PREPARATION PRESCRIPTIONS: AN ECONOMIC ANALYSIS[1]

David J. Moorhead and Coleman W. Dangerfield, Jr. [2]

Abstract. An economic analysis was performed to compare costs and returns from general vs. specific site preparation prescriptions on a recently harvested site in the Coastal Plain of south Georgia. The contractors initial site preparation recommendation, without the aid of a professional forester, was to shear-rake-bed the entire 161-ac site. Inspection of the site indicated that bedding was inappropriate for establishment. Instead, specific site preparation prescriptions were made across the tract. Prescribed treatments included chopping, shearing, and/or spot raking as required. Buffer strips were also maintained along all drainages. Actual costs were used in the analysis, and stand growth was modeled with respect to site index using YIELDplus (v 1.1c). Prescribed treatments resulted in cost savings of up to $42/ac over the most intensive treatments. Internal rate of return (IRR) and the annual equivalent value (AEV) were calculated for high vs. low prescribed site preparation treatments at four levels of site index, SI_{25}62, 65, 68, and 75. IRR for low cost prescribed treatments ranged from 10.5 percent at SI_{25}65 to 12.5 percent at SI_{25}75. In contrast, IRR for high cost recommendations ranged from 9.5 percent at SI_{25}62 to 11.4 percent at SI_{25}75. AEV payments for low cost treatments were found to increase by $2/ac over high cost treatments.

Introduction

Pine regeneration on nonindustrial private forest land (NIPF) lags behind annual harvest of these lands (Anonymous 1988). One factor determining the regeneration of cutover timberland is the high cost of site preparation that must be carried over the rotation. In many cases, NIPF landowners feel that successful pine regeneration requires intensive site preparation common to the intensive mechanical site preparation on many forest industry operations. However, the forest industry model may not be appropriate to many NIPF sites particularly when money is not available to landowners for intensive site preparation treatments.

Site preparation treatments which are uniformly applied across large tracts may result in reduction of site productivity, failure to adequately control competition and excessive expenditures to the landowner for inappropriate practices

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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askin et al., 1989). This study examined the value of site specific site eparation prescriptions on a recently cutover timber tract in the Coastal ain of Georgia.

Methods

A recently harvested upper Coastal Plain tract in Tift County, Georgia, s selected for analysis of the value of site specific site preparation eatments. The landowner had secured the services of a site preparation ndor who had site prepared and planted on the tract in the past. Howev-, the landowner was concerned about past activities on this property, es-cially the use of bedding on some of the upland portions of the tract. ds were previously installed along the slope causing excessive erosion d seedling mortality as the upland soils dried during summer droughts. e vendor quoted a price of $160/ac to site prepare and plant. Site prep-ation was to include shearing, raking, and bedding over the entire tract.

After meeting with the landowner and vendor, specific site preparation eatments were prescribed after evaluating the 161-ac tract. Individual escriptions were made on units as small as 1.2 ac. The prescription ocess included evaluation of residual debris, the composition of poten-al herbaceous and woody competition, soils and drainage, and compliance th voluntary Best Management Practices (BMPs) (Anonymous 1990). Two cost vels (high and low) of mechanical site preparation treatments included mbinations of chopping, shearing, and spot piling followed by broadcast rning were prescribed. The site was planted using slash pine (Pinus el-ottii Engelm.) seedlings at a density of 605 seedlings/ac. After plant-g, hexazinone and sulfometuron were applied in 4-ft-wide bands over the p of the seedlings at the broadcast rate of 2 pt of hexazinone and 3 of sulfometuron per acre by a backpack spray crew.

Economic efficiency was measured by computing the internal rate of re-rn (IRR) and annual equivalent value (AEV) for the high and low cost site ecific prescriptions. IRR measured returns to invested capital for each se. AEV expresses timber returns on a yearly annuity basis. Wood flow timates and financial calculations were performed using the microcomputer ogram YIELDplus (v 1.1c) (Hepp 1988).

Several financial assumptions were made for the analysis. Major as-mptions were:

- A 35-year rotation was chosen, using four levels of site index SI_{25} 62, 65, 68, 75, which represented the variation on the tract (Calhoun 1983). Initial planted density was set at 605 trees/ac. Two thinnings were included, the first at age 17 years and a second at 25 years. The stand was scheduled to be harvested by clearcutting at age 35 years. The YIELDplus (v 1.1c) growth model used was for a cutover slash pine plantation site.

- Provisions of the Tax Reform Act of 1986 were incorporated with a marginal tax bracket of 28 percent.

- A discount rate (opportunity cost) of 8 percent was chosen.

- Long run, average stumpage prices for the Georgia Coastal Plain were: pulpwood (5-10 inch dbh) $26/cd; chip-n-saw (10-12 inch dbh) $54.50/cd.; sawtimber (12-16 inch dbh) $180/MBF.

Results

Prescription treatments resulted in two levels of intensity and cost (Table 1). Sites which had little standing debris were chopped and spot raked at a cost of $74/ac. On sites where residuals remained after harvest, shearing and raking into piles was used at a cost of $116/ac. The high and low cost treatments were rather evenly divided across all ranges of site index with the exception of SI_{25}62, where the entire 65.6 ac in that productivity class required only the low intensity treatment (Table 2). Across the 161-ac tract, 58 percent (94.8 ac) was treated at a cost of $74/ac. Costs for seedlings, planting, and herbaceous weed control were constant for both high and low cost site preparation treatments (Table 1).

Table 1. Costs of two levels of prescription site preparation treatments and fixed costs of seedlings, planting, and herbaceous weed control.

Treatment	Cost/ac
	($)
Chop and spot rake	74.00
Shear and rake	116.00
Seedlings and planting ($17.30 seedling cost, $25.00 planting)	42.30
Herbaceous weed control	15.83

The actual cost of the prescribed site preparation treatments averaged over the 161-ac tract was $91.28/ac (Table 3). The vendors initial quote of $160/ac to site prepare and plant was based on a site preparation cost of $118/ac. With seedling and planting costs held constant and with the addition of herbaceous weed control at $15.83/ac (a cost not included in the vendor quote), the cost comparison between the vendor quote and the actual price by prescription was $175.83 and $149.41/ac, respectively. The prescription price, which was actually paid by the landowner, totaled $24,070.73 as compared with the vendor's quoted price (without herbaceous weed control) of $28,308.63 (Table 3). The use of prescription practices resulted in a direct savings to the landowner of $4,237.90.

A steady increase in wood flow was projected as SI_{25} increased from 62 to 75 ft (Table 4). The largest increase was between 68 and 75 where wood flow increased 16.2 percent, or 7.4 total cord equivalents.

Table 2. Total cost and acres of prescription site preparation treatments by site index.

Site $index_{25}$	Site preparation cost	Areas treated	Total cost*
	($)	(ac)	($)
62	74.00	65.6	132.13
62	116.00	--	--
65	74.00	3.1	132.13
65	116.00	21.2	174.13
68	74.00	20.9	132.13
68	116.00	39.7	174.13
75	74.00	5.2	132.13
75	116.00	5.4	174.13

* Site preparation + seedlings + planting + herbicide

Table 3. Site preparation cost comparision between vendor quote and prescription treatments.

	Site preparation cost/ac	Area	Total cost/ac[a]	Total cost/tract
	($)	(ac)	($)	($)
Vendor quote	118.00	161	175.83	28,308.63
Prescription	91.28[b]	161	149.41	24,070.41

[a] Site preparation + seedlings + planting + herbicide

[b] Average of all treatments

Internal rate of return for the low cost case ranged from 10.5 percent for $SI_{25}62$ to 12.5 percent at $SI_{25}75$ (Table 5). For the high cost case, IRR ranged from 9.5 percent for $SI_{25}62$ to 11.4 percent at $SI_{25}75$. Therefore, for each case, IRR steadily increased as site index increased. For each site index, the difference in IRR between the low and high cost site preparation prescriptions remained approximately 1.0 percent. Improvements in IRR were constant across different levels of site index with changes in site preparation costs.

Changes in AEV were similar to those for IRR (Table 5). Annual annuity payments increased approximately $2/ac between the low and high cost treatments with the same site index. Also, AEV/ac steadily increased from $26.26 at SI_{25}62 to $42.76 at SI_{25}75. Total cash flow is shown to be greater in the low cost prescription as compared to the high cost prescription (Table 6). This results from the $42/ac difference between the high ($116) and low ($74) prescription treatments. The extra $42 cost occurs at the beginning of the rotation while harvest revenues do not occur until the stand is thinned and finally harvested.

Table 4. Wood-flow per acre by site index for planted slash pine plantations on cutover sites 35-year rotation, south Georgia, 1989.

Site index	Pulpwood	Sawtimber	Total cords
(ft/25 yr)	(cord)	(mfb[a])	(equivalent)
62	20.4	8.0	39.7
65	21.7	9.0	42.6
68	23.0	10.0	45.6
75	25.1	13.1	53.0

[a] Thousand bd ft

Table 5. Investment analysis for planted slash pine plantations on cutover sites by site index and level of site preparation and planting cost, per acre, after tax (35 percent), 8 percent discount rate, 35-year rotation, south Georgia, 1989.

Site index	Cost[a]	Internal rate of return	Annual equivalent value
(ft/25 yr)	($/ac)	(percent)	($/ac)
62	Low	10.5	26.26
	High	9.5	24.03
65	Low	10.9	28.94
	High	9.9	27.00
68	Low	11.3	32.00
	High	10.3	30.06
75	Low	12.5	42.76
	High	11.4	40.83

[a] Total planting cost/ac: low = $132.13; high = $174.13.

Table 6. Before tax cash-flows for low and high investment planted slash pine stands, site index 68, constant dollars, south Georgia, 1989.

Item	Investment	
	Low	High
	($)	($)
Expenses		
Planting	-132.13	-174.13
Management	- 32.48	- 32.48
Harvest	-219.37	-219.37
Revenues		
Pulpwood	394.41	394.41
Chip-n-saw	1239.12	1239.12
Sawtimber	560.13	560.13
Total	1809.68	1767.68

Discussion

Examination of the tract indicated that the broad site preparation reatment initially recommended by the vendor (shear-rake-bed) was not ustified. In particular, the use of bedding was not appropriate on the ajority of the tract. The maintenance of Streamside Management Zones in ompliance with voluntary BMPs reduced the number of acres within the tract hat required bedding. Other areas of the tract, particularly the 65.6 ac f SI_{25}62 land, did not require bedding as this area was a well drained, olling upland and improper application of site preparation practices could educe productivity (Gaskin et al., 1989).

Bedding has become so common in the Coastal Plain that it is frequently pplied to uplands or other less obvious adequately drained sites as had ccurred in the past on this landowners property. The practice is intended o provide localized drainage of surface moisture to enhance seedling esablishment (McKee and Shoulders 1974, Derr and Mann 1977). Bedding resonses are often variable (Cain 1978, Wilhite and Jones 1981). Early rowth of seedlings on beds is thought to be enhanced by the concentration f nutrients and organic matter in the bed, however this benefit is usually hortlived (Pritchett and Smith 1974; Haines et al., 1975). Some early edding responses may have also reflected reduction of competition on the ed which may have benefitted seedling establishment for a short time after utplanting. To achieve this result, the application of herbaceous weed ontrol is justified in place of bedding on sites which do not have limitaions to surface drainage or the presence of standing water tables near the oil surface.

Within the prescribed site preparation treatments, the cost differential was $42/ac between the high and low treatments. The costs of the prescription treatments were similar to those averages reported for the region (Straka et al., 1989). When examined in relation to site index, the IRR indicated that a 1-percent increase could be achieved by reducing the required site preparation cost. This is dependent on the need to provide competition control and planting access. In the past, intensive mechanical site preparation was require to reduce competition and facilitate machine planting (Guldin 1982). However, with the increased use of herbicides and handplanting, sites can be adequately prepared to control competition without intensive mechanical treatments. One drawback for many landowners is the requirement for prior planning to implement these alternative site preparation methods. The use of herbicides requires application at specific times in relation to the type of herbicide and application method required (Miller 1989).

Conclusions

The use of site specific site preparation prescriptions resulted in direct cost savings to the landowner of $4,237.90. This actual savings was realized by the landowner since he had reserved a portion of the harvest income, based on the vendor quote, to site prepare and regenerated the cut-over tract. The practice of reserving a portion of the harvest income is highly recommended at each harvest to insure that costs of regeneration are available. Additionally, IRR improved and AEV was enhanced $2/ac when lower site preparation costs were realized. Past practices which had resulted in serious soil erosion and unnecessary site preparation costs were eliminated by the use of site preparation prescriptions based on residual material present after harvest, composition of probable competition, soil and drainage characteristics, and adherence to BMPs. In order for landowners to benefit from these practices, planning prior to timber harvests is required and would be facilitated by the development of a comprehensive forest management plan.

Acknowledgments

The authors wish to thank Mike Brumby of Tifton, Georgia, for his cooperation in this study.

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LONG-TERM EFFECTS OF THINNING ON STEM TAPER OF OLD-FIELD, PLANTATION LOBLOLLY PINE IN THE PIEDMONT[1]

Larry E. Nix and Tom F. Ruckelshaus [2]

Abstract. Effects of residual stocking levels on stem taper of trees in a long-term, old-field plantation thinning study on the Clemson Experimental Forest in the South Carolina Piedmont were investigated. Taper of individual trees in 1-inch diameter steps was measured with a tripod-mounted optical dendrometer equipped with a clinometer. Dendrometer measurements were compared with caliper measurements of a subsample of felled trees and found satisfactorily accurate except in the live crown region of stems where large branches interfered with visibility of stem profiles. Effects of low, medium, and high basal area residual stocking levels on stem taper were analyzed. Stem taper differed statistically among after-thinning stocking levels in lower and upper boles. Stem taper of trees in low and medium stocking plots was less than that of high stocking plots in the lower bole positions but was higher in upper bole positions. Results indicate that heavy or moderate thinning does not reduce bole quality as measured by tree length stem taper, and, in fact, may actually improve form in lower boles as compared to light or no thinning.

Introduction

Forest stands that are grown on longer rotations in the South to produce higher quality products are often thinned to provide periodic income, salvage impending mortality, and concentrate growth on better quality residuals. Among the quality criteria set for such rotations are size, straightness, clearness of bole, and minimal stem taper so as to produce the maximum volume possible of valuable sawtimber, veneer, poles and pilings. Stem taper is a product quality criterion that not only affects the structural qualities of valuable pole-type products of long rotations, but also influences the volume and value of products that can be manufactured from a tree of a given diameter and height. For example, a change of one percent in Girard form class, a commonly used measure of the taper in sawtimber trees, can alter the board foot volume of the tree by approximately 3 percent (Mesavage and Girard 1946). Form class, although still frequently estimated in the field and used to calculate sawtimber volumes, does not adequately describe the taper of trees along the entire merchantable length. It is poorly suited for use in modern, computer-compatible volume equations (Wiant and Castaneda 1977; Bennett et al., 1978). Stem taper functions, which assume that the tree stem is a definable solid of revolution, may provide the best prediction system for estimating tree volumes for

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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almost any assortment of products (Farrar and Murphy 1987). Taper functions, however, need to be developed for the various populations of trees that result from the implementation of silvicultural practices, such as thinning, especially if long-rotation, high value products are desired.

Previous studies of long-term thinning effects on stem taper in old-field, loblolly pine (Pinus taeda L.), indicated that taper differs among diameter classes of the same age and is affected by both site quality and thinning level (Shearin et al.,1985; Nix et al., 1987). These taper studies were actually ancillary to a broader long-term study of growth and yield in thinned loblolly pine stands of the Piedmont and the measures of taper were thought to be crude, at best. The present study was undertaken as a followup to these earlier studies in the hope of using a more precise system of taper measurement and developing more accurate taper functions for use in assessing long-term thinning effects on taper and product yield in these stands.

Materials And Methods

Clemson University's Department of Forest Resources has maintained a long-term thinning study for the past 35 years in old-field, Piedmont, loblolly pine plantations. These stands were established on abandoned farmlands on the Clemson Experimental Forest in upper South Carolina in the late 1930s by the Works Progress Administration of the Roosevelt era (Goebel et al., 1974). Study plots are now 50 years old and have been thinned five to seven times to specified levels of residual basal area, starting at about age 15. Thinnings have been conducted at 5- to 8-year intervals or whenever plot basal areas exceeded the specified plot residual by 25 ft^2 /ac. Residual basal areas range from 75 to 135 ft^2/ac and plot site index ranges from 72 to 98 (base age 50 years). Unthinned control plots averaging 175 ft^2/ac basal area are located adjacent to each set of thinning plots. The exact thinning levels are not replicated at all locations and site index varies even among plots at the same location, thus necessitating grouping plots into low, medium, and high residual basal area levels and treating site index as a covariate in statistical analyses.

Diameters of all trees were measured ($\pm$ 0.1 inch) with a steel tape at a permanently marked height of 4.5 ft and total heights were estimated ($\pm$ 1.0 ft) with a clinometer. Tree taper was determined by using a tripod-mounted optical dendrometer (Wheeler pentaprism) with an attached clinometer to measure the height to each successive 1-inch reduction in diameter, starting at the 4.5 ft height measurement of each tree on all plots. A subsample of 54 trees representing most dbh classes, thinning levels, and site indexes, was measured with the dendrometer, then felled and measured in an analogous manner with calipers to determine the accuracy of the dendrometer in measuring taper of standing trees. Tree taper curves were developed using a computerized general linear models procedure (SAS 1985) with a quadratic regression model and a third-degree polynomial splining procedure to generate curves for comparisons. Comparisons of taper as related to method of measurement, diameter class, and thinning level (residual basal area) were done with the paired t-test and the students' t-test (SAS 1985) at each taper step or 1-inch reduction in diameter with height. There were 451 total trees involved in the study.

Results And Discussion

A comparison of dendrometer measurements of taper in standing t with that of caliper measurements of felled trees indicates that the drometer measurements are quite accurate except at taper steps six to s (Fig. 1) which are at 60-70 ft height. At this height, the methods di at the 0.035 level of probability using a paired t-test. Also, at height on most of the trees, large branches often make it difficult to curately use an optical dendrometer. The error is not in a valuable tion of the tree and appears to be consistent, thus, will likely allow ative comparisons of differences in taper among treatments or diam classes.

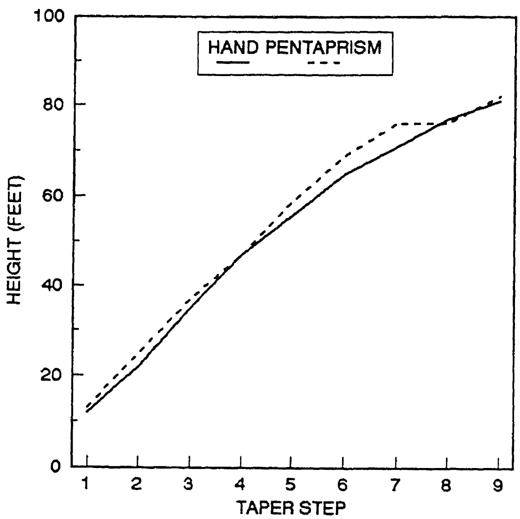


Figure 1. Comparison of stem taper measurements of standing (pentaprism) and felled (hand) old-field loblolly pines in the SC Piedmont (taper steps are 1-inch reductions in diameter outside bark).

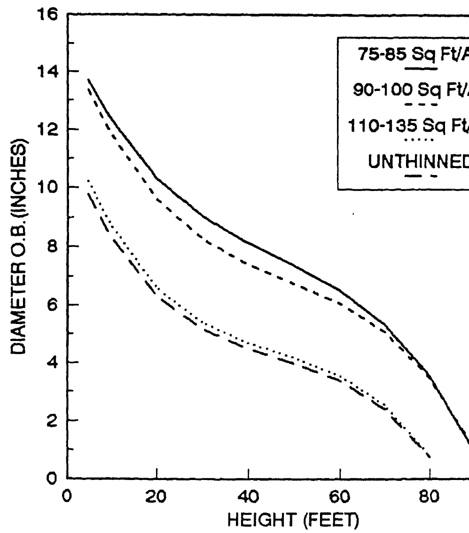
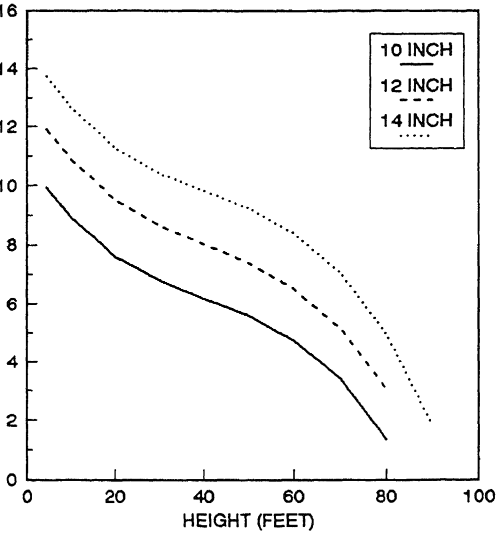


Figure 2. Stem taper of thin treatments at age 50 of old-f loblolly pine in the SC Pied (legend indicates residual b areas after thinning; unthi control = 150-200 ft²/ac).

A comparison of stem taper curves among levels of residual stoc (Fig. 2) does not clearly show differences in taper except perhaps in upper bole where the larger diameter trees of the lower stocking levels pear to taper more than the smaller diameter trees of higher stocking els. This higher rate of taper might naturally occur because larger ameter trees are essentially the same height as smaller diameter trees even-aged stands. Taper curves for the average diameter classes on study plots (Fig. 3) show much the same relationship and are too gen for specific comparisons. However, comparisons of the actual rates of per in inches of diameter per foot of height are shown in Figures 4 a



gure 3. Stem taper of mean di-
eter classes in 50-year-old lob-
lly pine thinning treatments in
e SC Piedmont.

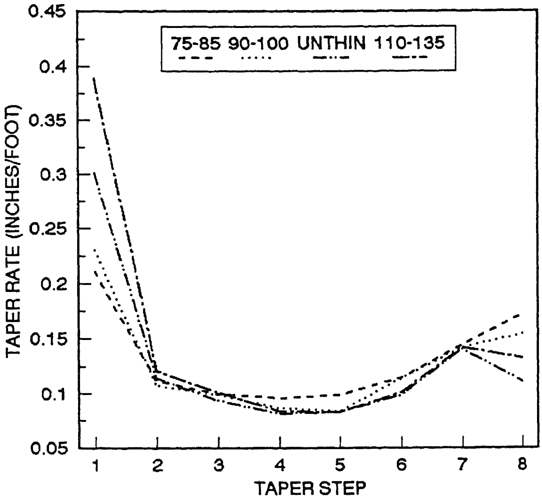


Figure 4. Average rates of stem taper at each taper step for different stand thinning levels at age 50 for old-field loblolly pine in the SC Piedmont (taper steps are 1-inch reductions in diameter, outside bark; legend indicates residual basal area in ft²/ac after thinning).

: thinning levels and diameter classes, respectively. Trees of the low
l medium residual stocking levels exhibit less taper in the lower bole
: more in the mid and upper bole than do those of the high residual lev-
; and the unthinned plots (Fig. 4). These differences in rate of taper
e signifiant at the 0.05 level of probability at taper steps one, two,
re, six, and seven using the students t-test (SAS 1985). It is possible
it diameter differences induced by thinning may be responsible for these
fferences in taper rates. However, the relation of stem taper to diamet-
class over a wide range of diameters is not very clear (Fig. 5). Aver-
e taper rates appear to be less in larger diameter classes in the lower
le, but higher in these same diameter classes in the middle and upper
le. These differences are significant at the 0.05 level only at taper
eps one, five, six, and seven which correspond to lower, mid- and upper-
le positions. Oddly enough, the greatest taper in the lower bole is ex-
oited by trees from the high residual stocking levels and smaller diamet-
class (Fig. 4, 5), but this difference in taper reverses in mid- and
per-boles. These results confirm the conclusions of an earlier study
x et al., 1987) concerning the effects of thinning on lower bole form
rard form class) and appear to indirectly corroborate the findings of
rrar and Murphy (1987) regarding the influence of tree crown ratio on

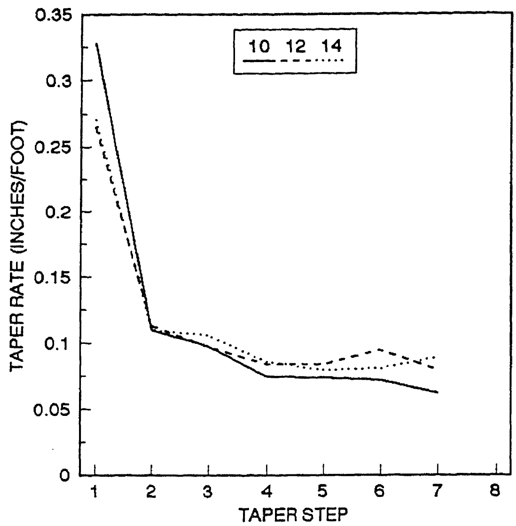


Figure 5. Average rates of stem taper at each taper step for different diameter classes at age 50 of old-field loblolly pine in the SC Piedmont (Taper steps are 1-inch diameter reductions; legend indicates diameter classes in inches).

stem taper in lower bole positions of trees of similar diameters. These authors noted that higher crown ratio produced greater overall tree taper especially in mid-bole, but less taper in the lower boles of shortleaf pine (P. echinata Mill.). The loblolly pines of the present study growing under low and medium residual stocking levels certainly would have higher crown ratios than those of the higher stocking levels and do exhibit reduced taper in lower bole positions (Fig. 4).

The influence of site index on these taper relationships must be considered since thinning treatments are not fully replicated across all site indexes. The low and medium residual stocking level plots average 91 ft in height whereas the high stocking and unthinned plots average 83 ft. With an average difference in height of 8 ft across all diameter classes, average overall stem taper would be less in the taller trees regardless of residual stocking levels. The height difference may also influence diameter class effects on taper as more larger trees would have contributed to the measurements from low and medium stocking levels and, of course, are taller because of the higher average site index. When the effects of diameter class were tested within thinning levels using the t-test with 2-inch diameter classes to gain more tree measurements in each class, only the trees in the lowest residual stocking level exhibited a significant (at the 0.05 level) effect of diameter on taper. Interestingly, this effect occurred at taper step one, where 10-inch trees tapered more than 12- and 14-inch trees, and at taper step seven where the reverse occurred, as would be expected (Fig. 5).

These results certainly make a strong, even if indirect, case for adding crown ratio measurements to the standard diameter and height measurements as suggested by Farrar and Murphy (1987) for purposes of accurately estimating standing tree volumes. At least one conclusion may be derived from the present study, that thinning to heavy or moderate levels will not greatly reduce bole quality as measured by stem taper, and may, in fact, improve form in the lower more valuable portion of the tree.

United States
Department of
Agriculture

Forest Service

**Southeastern Forest
Experiment Station**

General Technical Report
SE-70

Proceedings of the
Sixth Biennial Southern Silvicultural Research Conference

Memphis, Tennessee
October 30 - November 1, 1990

Volume 1

GROWTH OF LOBLOLLY PINE UNDERPLANTED WITH CLOVERS IN SOUTHERN ARKANSAS [1]

Frank A. Roth. II, J. Mike Phillips, and Robert J. Colvin [2]

Abstract. Growth of loblolly pine (*Pinus taeda* L.) thinned to "sudden-sawlog" spacings and underplanted with clovers is being studied. Pine plantations, originally planted at an 8- by 10-ft spacing in 1978, were thinned to 100 and 250 trees/ac and pruned to a height of 8 ft in the spring of 1987. Plots were burned, disced, fertilized, and seeded to clovers in the fall of 1987. Seven clover varieties were used. By spring of 1988, all clovers provided excellent ground cover under the low tree density. However, under the high tree density, excellent ground cover was obtained with only four varieties. By spring of 1990, all clovers had disappeared under both densities. Tree diameter and height growth during the 1988 and 1989 growing seasons varied significantly by tree density. Mean diameter growth at the low density was 2.4 inches, and at the high density, 1.4 inches; while mean height growth at the low density was 4.9 ft and at the high density, 6.9 ft during the 2-year period. By the end of 1989, high density trees had reached crown closure and had begun natural pruning, while low density trees had not reached crown closure.

Introduction

Loblolly pine (*Pinus taeda* L.) is the most frequently planted commercial timber species in southern Arkansas because of its high growth potential on a wide variety of sites and good markets. Traditionally, the landowner's profit from planting pines comes more than 30 years later when sawtimber is harvested. The long-term nature of the investment needed to grow pine sawtimber often is a discouragement to nonindustrial private forest landowners. Investments in planting pines might be made more attractive by shortening the amount of time needed to produce a crop of sawtimber, or by providing for an annual income from the pine plantation until the sawtimber crop matures.

The time needed to produce a crop of loblolly pine sawtimber can be shortened by "sudden-sawlog" management. "Sudden-sawlog" rotations in loblolly pine were first investigated by Reynolds (1980) at the Crossett Experimental Forest in southern Arkansas. With this technique, pine stocking was reduced to 100 crop trees/ac in one or two thinnings at age 9 or 12. Burton (1982) summarized the results of the "sudden-sawlog" study at Crossett through age 33. He found that "sudden-sawlog" management produced

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Extension Forester, Associate Professor, and Research Specialist, Univ. Arkansas, Hope.

oout 5,000 bd ft/ac, Doyle scale, by age 24, nearly 10 times the volume roduced by conventional management.

Annual incomes can be produced by growing forage crops along with pine rees. Researchers have tested varieties of legumes that seem to have good orage characteristics and the ability to survive under a forest canopy in ne Gulf Coastal Plain. Watson et al. (1984) found that legumes vary in neir ability to tolerate shade. Johnson et al. (1986) reported the es- ablishment of subterranean clover (Trifolium subterraneum L.) under 30- to 5-year-old loblolly-shortleaf pine stands. Clover yields were inversely elated to canopy density. Loblolly pine seedlings were established in ubterranean clover pastures by Pearson et al. (1990). They found that af- er 3 years, browsing and trampling injury to the pines was not excessive ven with unrestricted grazing. Although clovers have been grown success- ully in association with loblolly pine seedlings and mature timber stands, ittle is known about growing clovers under midrotation pines, 10 to 20 ears old.

In order to shorten sawtimber rotations and produce some annual income t the same time, loblolly pine plantations might be thinned to "sudden- awlog" spacings and forage legumes established. The present study was ndertaken to evaluate the growth of loblolly pine at two "sudden-sawlog" ensities, and the growth of legumes under the pine canopies.

Methods

The study area is located on the University of Arkansas' Southwest Re- earch and Extension Center, near Hope, Arkansas. Soils, of the Sawyer and ilcox series, are fine textured and slowly permeable. Loblolly pine site ndex is about 90 ft at age 50. The study was established in 1987 in an rea originally used for a grazing study. Loblolly pine seedlings were lanted at an 8- by 10-ft spacing in tall fescue (Festuca arundinacea chreb.) and common bermudagrass [Cynodon dactylon (L.) Pers.] pastures uring February 1978. After grazing was terminated in the spring of 1984, ine survival ranged between 250 and 400 trees/ac.

The experimental design was a split-split-split plot design with four eplications. Each 8-ac replication was divided into two tree densities, 00 and 250 trees/ac; each density was divided into prescribed burning and o burning treatments; and each burning treatment was divided into eight, .25-ac plots to accommodate the planting of seven clover varieties plus a ontrol. The clovers included crimson clover (T. incarnatum L.) varieties Dixie' and 'Tibbee;' rose clover (T. hirtum All.) variety 'Wilton'; arrow- eaf clover (T. vesiculosum Savi) variety 'Yuchi'; and subterranean clover arieties 'Mt. Barker,' 'Woogenellup,' and 'Meteora.'

Trees were thinned to the desired densities and pruned to a height of 8 t in the spring of 1987. Tops and limbs from the thinning and pruning ere removed from the site. In the fall of 1987 all plots were burned, isced, and fertilized with 200 lb/ac of triple superphosphate (0-46-0). ollowing site preparation, clovers were planted in all plots except the

controls. Prescribed burning was not scheduled until the fall of 19 therefore, herbaceous weeds and grasses were controlled by mowing tw each year. Clovers were evaluated each spring for forage production. T diameters and heights were measured each year during the dormant season.

Results And Discussion

By the spring of 1988, clovers had become established in most plo Under the low tree density (100 trees/ac), all clover varieties provi excellent ground cover. However, under the high tree density (250 tre ac), excellent ground cover was provided by only four clover varieti Wilton rose, Tibbee crimson, and by Mt. Barker and Woogenellup subterr eans. This difference may be due to variation in shade tolerance am clover varieties. Measurements taken with a spherical densitometer November 1988 revealed that crown densities averaged about 60 percent the low tree density and 90 percent for the high tree density. By spring of 1990, all clovers had disappeared under both tree densities. failure of the clovers may be attributable to the accumulation of orga material on the forest floor. Under the high tree density, the soil s face was covered with a 3-year accumulation of pine straw, while under low tree density, the clippings from mowing the weeds and grasses tended accumulate. Another factor that may have caused the decline of the clov was an extreme cold period in December 1989, when the temperature drop below 0° Fahrenheit. In the fall of 1990, a prescribed burn was conduc to remove the material from the forest floor. This has resulted in clov germinating once again in many plots; however, it is too early to determ if the clovers have become reestablished.

The diameter growth of the trees differed significantly between t densities during the first two years of the study (Table 1). At the end the 1987 growing season, the 10-year-old plantations had average diamet of 6.5 inches at both tree densities. However, by the end of the 1 growing season, the low density trees had grown an average of 2.4 inches diameter, while the high density trees had grown only 1.4 inches. The d ference in diameter growth suggests that there is enough competition am the high density trees to restrict the diameter growth of the individ trees.

The height growth of the trees differed significantly between tree d sities during the first two growing seasons of the study as well (Table At the end of the 1987 growing season, the 10-year-old plantations thin to 100 trees/ac averaged 26.9 ft tall, and those thinned to 250 trees averaged 29.9 ft tall. This difference in initial height may be related differences in stand density prior to the application of the thinn treatments. By the end of the 1989 growing season the high density tr had grown an average of 6.9 ft in height, while the low density trees grown only 4.9 ft. The difference in height growth suggests that there not yet enough competition among low density trees to restrict crown dev opment. At the end of the 1989 growing season, the high density trees reached crown closure and had begun the natural pruning of limbs above 8-ft pruning height. At the same time the low density trees had not rea ed crown closure. This indicates that at least some of the height gro

otential of the low density trees was diverted to the growth of large, ower limbs.

Table 1. Effects of "sudden-sawlog" spacing on diameter growth of loblolly pine after 2 years.

Trees/ac	Rep	Diameter 1987	Diameter 1989	Diameter Growth
		inches		
100	1	7.0	9.2	2.2
	2	6.4	8.9	2.5
	3	5.7	8.2	2.5
	4	7.0	9.4	2.4
	Mean	6.5	8.9	2.4
250	1	6.6	8.1	1.5
	2	6.3	7.7	1.4
	3	6.7	8.1	1.4
	4	6.5	7.9	1.5
	Mean	6.5	7.9	1.4

Table 2. Effects of "sudden-sawlog" spacing on height growth of loblolly pine after 2 years.

Trees/ac	Rep	Height 1987	Height 1989	Height Growth
		ft		
100	1	28.4	33.4	5.0
	2	27.4	32.7	5.3
	3	22.9	28.0	5.1
	4	28.8	33.0	4.1
	Mean	26.9	31.8	4.9
250	1	28.7	35.5	6.8
	2	31.6	38.6	7.0
	3	30.6	37.3	6.6
	4	28.9	35.9	7.0
	Mean	29.9	36.8	6.9

Conclusions

For loblolly pine plantations between 10 and 12 years old, preliminary results of this study suggest: (1) that as stand density increases diameter growth decreases, and height growth increases; (2) that it may be difficult to establish clovers beneath stands of this age, and; (3) that in order to maintain clovers in these stands, an annual prescribed burning program may be necessary.

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PREDICTION OF YIELD BY LOG GRADE FOR RED OAK-SWEETGUM STANDS IN MISSISSIPPI [1]

Keith L. Belli, Thomas G. Matney, and John D. Hodges [2]

Abstract. Work is currently underway at Mississippi State University to develop growth and yield prediction systems for mixed stands of red oak-sweetgum. Discriminant analysis, using both stand- and tree-level information, was employed to categorize trees from a set of 150 permanent plots into classes based on their maximum log grade. (Forest Service specifications for log grade are used throughout.) Within each of these classes, a set of equations was then developed to predict the distribution of total tree volume by log grade.

Introduction

Mississippi's bottomland hard-
l resource is receiving an in-
asing amount of attention. One
the current difficulties in man-
ng this resource is a shortage of
ormation concerning growth and
ld for the principal bottomland
lwood species, mainly the red oak
cies group (Quercus sp.) and
etgum (Liquidambar styraciflua
. Even such rudimentary yield
els as variable density yield
les are rare; value, or grade,
liction models are nonexistent.

The value of hardwood trees can
characterized at three levels.
st is the value, or grade, of the
log, often referred to as tree
le. Second is log grade for each
the logs in the tree. Finally,
re is the grade of the lumber ac-
lly recovered from each log. Past
orts to predict the value of
lwood stands mainly have focused on the estimation of tree grade distributions within a stand (e.g., see Trimble 1965, Ernst and Marquis 1979, Dale and Brisbin 1985, and Myers et al. 1986), or on lumber grade recovery from butt logs of various grades (see Hanks et al. 1980, and Yaussy and Brisbin 1983). Much of this research has been restricted to upland species in the Northeastern states. These studies have not considered estimation of the grades of logs above the butt log, nor have they attempted to estimate the proportion of a tree's total volume contributed by each log by grade.

Recent work by Reed et al. (1987) and Lyon and Reed (1987) on sugar maple (Acer saccharum Marsh.) in Michigan provides the only example of a simultaneous examination of tree grade prediction and volume apportionment by log grade for whole-tree logs. A similar investigation would be of great benefit to managers of Mississippi's hardwood resource. The objective of this study was to develop a prediction system for southern bottomland hardwoods that is capable of: (1) estimating the grade of individual trees given tree and stand characteristics; and (2) apportioning total tree volume into categories of log grade.

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aper presented at Sixth Biennial
thern Silvicultural Research Con-
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1990.

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Data

Data for the study were taken from a set of 150 permanent plots located in red oak-sweetgum stands in minor stream bottoms in central Mississippi. The four primary species of red oak found in such stands were cherrybark (Quercus pagoda Raf.), water (Q. nigra L.), willow (Q. phellos L.), and shumard (Q. shumardii Buckl.). Plots were located in stands with at least 75 percent of the total basal area made up of sweetgum or red oak, with a minimum of 20 percent basal area for each species, or species group. Although the minimum plot area was set at 0.1 ac, plot size varied to insure that no less than 50 trees were measured on each plot. (Trees < 3.5-inch dbh were not measured.)

In addition to typical tree and stand-level information (e.g., species, dbh, total height, stand age, site index, etc.), each tree on a plot was graded using USDA Forest Service grading standards for hardwood factory lumber logs (see Rast et al. 1973). The information provided by grading these trees included the number of log sections plus the length and grade for each section. Section grade was designated as 1, 2, 3, 4, and 5 for factory grades 1, 2, and 3, tie and timber grade, and cull (or nonmerchantable), respectively. To improve the distribution of graded trees across dbh classes, supplemental data on tree grade were collected from an additional 554 red oak trees located within the same stands as the plots. The final database included information on over 8000 trees: 3650 sweetgum, 1092 cherrybark oak, 770 willow oak, 408 water oak, 108 shumard oak, 226 other oaks, and 1850 other hardwoods.

Methods

The volume of the log sections in cherrybark oak and sweetgum trees was estimated using profile equations from Matney et al. (1985). These equations were chosen because they were developed using trees from the same stands as those containing the permanent plots, and they do not require upper stem diameter measurements. Given only section length, tree dbh, and knowledge of the position of the particular section within the tree, the diameter at 4-foot intervals along the section was calculated from the profile equation. Tree volume between these intervals was estimated using Smalian's formula, and the results were summed for the section to provide total section volume in cubic feet. The results then were converted to volume in board feet (international, ¼-inch scale). Finally, the process was repeated for each section in the tree to arrive at an estimate of total tree volume.

Unfortunately, similar stem profile equations were not available for the other main oak species. Other potential volume estimation equations, such as those from Schlaegel (1981) for willow oak, required upper stem diameter measurements not available from the data set. Hence, the methodology developed for estimating the proportion of a tree's volume by grade currently applies only to cherrybark oak and sweetgum. The procedure may be expanded easily once suitable volume equations for the other oak species are developed. Therefore, for simplicity, tree grade prediction results also will be presented for cherrybark oak and sweetgum only, even though the other red oak species were included in the tree grade prediction analysis.

e Grade Prediction

The prediction of tree grade becomes important to the valuation of hard-d stands only when such information is not readily available from inven-y data. Methods of grade prediction are not intended to replace the ctice of tree grading during an inventory or timber appraisal cruise. , the ability to predict the distribution of tree grade in a given stand be a vital factor in the comparison of management alternatives for h-value hardwood stands.

For the purpose of this study, tree grade was defined as the maximum log lity found in a given tree. In practice this is roughly equivalent to ting tree grade equal to the grade of the butt log, but adjusts for the asional but potentially important instance where the butt log fails to be a higher grade than the second log in the tree. Such a situation is ely to occur only in large trees or in trees where the butt log has been aged.

The nature of the dependent variable, tree grade, lends itself well to use of linear discriminant analysis (see Lyon and Reed 1987). There are inite number of mutually exclusive grade classifications specified prior data collection. These classifications also are related by definition to criminator variables pertaining to tree size requirements and indirectly certain stand characteristics.

A stepwise linear discriminant analysis routine was used to identify po-tial independent variables effective for predicting tree grade. When ecting variables for the final discriminant function, consideration was en to model simplicity, as well as ease of data acquisition. The func-ns were not simply a reiteration of those variables selected by the sta-tical software.

ume Distribution

After section volumes were calculated for all trees, it was possible to ress the proportion of a tree's total volume falling into a particular grade. A graphical examination of the resulting distribution of volume grade for individual trees and for trees grouped by dbh class revealed a sistent pattern that could be characterized by the modified exponential ction:

$$P_G = b_1 e^{b_2(G-1)}, \qquad [1]$$

re, P_G = percent volume (gross bd ft, international, ¼-inch scale) log grade G,
G = log grade category (limited to G = 1, 2, 3, 4, 5), and
b_i = coefficients to be estimated for each species.

ation [1] can be treated as a discrete distribution function for volume log grade, with the restriction that:

$$\sum_{G=1}^{5} P_G = 1.0 \qquad [2]$$

Log grade data first were stratified by tree grade before attempting to fit equation [1], since such a procedure has been shown to improve volume prediction (Reed et al. 1987). The stratification process made it necessary to revise equation [1] slightly to preclude the prediction of volume in log grades that, by definition, can not exist in a tree of a particular grade. For example, equation [1] will allow a non-zero value for log grade one volume in a grade two tree, an event that contradicts the definition of a grade two tree. Therefore, equation [1] was modified as follows:

$$P_G = b_1 e^{b_2 (G-T)}, \qquad [3]$$

where, T = tree grade category within which log grade volume percentages are being predicted.

Nonlinear regression procedures (Quasi-Newton method) then were used to fit the equation to data grouped into 2-inch diameter classes (chosen to coincide with the typical classes used to inventory stands in Mississippi). The loss function was adjusted to constrain the results to satisfy equation [2].

Results

Tree Grade Prediction

Both species required only two discriminator variables, dbh and relative basal area (defined as the ratio of a tree's basal area to the basal area/ac of the stand in which the tree was found), to predict tree grade (Table 1). Other combinations of variables produced comparable results, but were rejected for practical reasons. For example, the difficulty and expense of measuring such factors as total, or merchantable, tree height made these variables less desirable than dbh or basal area for the final function.

Table 1. Discriminant functions[a] for predicting tree grade of cherrybark oak and sweetgum.

Cherrybark oak

$$l_1 = 4.89450*dbh - 2158.85939*RELBA - 32.36441$$
$$l_2 = 4.39703*dbh - 2088.09963*RELBA - 23.90176$$
$$l_3 = 3.75209*dbh - 1881.88749*RELBA - 16.55070$$
$$l_5 = 2.64836*dbh - 1373.58928*RELBA - 8.07015$$

Sweetgum

$$l_1 = 4.43953*dbh - 1339.29273*RELBA - 32.23311$$
$$l_2 = 5.32972*dbh - 3603.19890*RELBA - 24.22924$$
$$l_3 = 5.21389*dbh - 4165.02024*RELBA - 19.12057$$
$$l_5 = 3.72009*dbh - 3527.85098*RELBA - 8.20021$$

[a] l_i = linear discriminant function for tree grade i
dbh = diameter at breast height (in.)
RELBA = relative basal area as defined in text

n. The overall classification success rate for these functions was 74.3 85.5 percent for cherrybark oak and sweetgum trees, respectively. This cess rate, however, varied by category. It should be noted that the ctions allow trees to be classified into four, rather than five, tree des. Grade four trees were omitted from the analysis since they were tually nonexistent in the database for either species.

ume Distribution

The regression results for cherrybark oak are given in Table 2. For de one and two trees, the success of equation [3] in accounting for the iation in volume distribution among log grades (as judged by the index of) increased with increasing dbh class. There also was a gradual shift in dicted volume proportion from poorer to better grade logs as dbh class reased. This shift is indicated by the monotonic increase in the b_1 coicient and the corresponding decrease in the b_2 coefficient. For grade ee cherrybark oak, the results were exactly the opposite. As dbh class reased, the fit of equation [3] became poorer and volume proportion fted to the less desirable log grades.

Table 2. Regression results for predicting the proportion of cherryback oak tree volume[a] by log grade for trees that have been categorized by tree grade.

Dbh class	Tree grade one			Tree grade two			Tree grade three		
	b_1	b_2	Index of fit	b_1	b_2	Index of fit	b_1	b_2	Index of fit
(inch)									
10							.9629	-3.292	.958
12				.5318	-.6891	.413	.8481	-1.864	.817
14				.5586	-.7587	.650	.7345	-1.266	.775[c]
16	.4374	-.5187	.467	.5958	-.8597	.670			
18	.4481	-.5416	.530	.6298	-.9574	.701			
20	.4990	-.6541	.662	.7322	-1.303	.778			
22	.5303	-.7262	.666	.8303	-1.770	.833[b]			
24	.6568	-1.060	.779						
26	.7407	-1.346	.815						
28	.7494	-1.381	.806						
>29	.8211	-1.720	.812						

[a] Volume in board feet, international 1/4-inch scale.
[b] This dbh class was an aggregation of all Grade 2 trees > 21 inches.
[c] This dbh class was an aggregation of all Grade 3 trees > 13 inches.

For sweetgum, the fits tended to be poorer overall than for cherrybark (Table 3). Unlike oak, the fit index associated with poorer grade trees ded to be higher than for the better grade trees. This likely is a rection of the greater number of trees in the grade three category than in her grade one or two. Results for grade one sweetgum were similar to se for cherrybark oak in that the proportion of volume predicted to fall o the better log grades increased with dbh class. However, this trend reversed for both grades two and three sweetgum, rather than for just de three as in the oak results.

Table 3. Regression results for predicting the proportion of sweetgum tree volume[a] by log grade for trees that have been categorized by tree grade.

Dbh class	Tree grade one			Tree grade two			Tree grade three		
	b_1	b_2	Index of fit	b_1	b_2	Index of fit	b_1	b_2	Index of fit
(inch)									
10							.9550	-3.100	.925
12				.5339	-.6946	.637	.8176	-1.672	.780
14	.3040	-.2372	.198	.4947	-.5964	.535	.5649	-.6731	.451[c]
16	.3639	-.3636	.367	.4611	-.5145[b]	.411			
18	.3693	-.3748	.427						
>19	.3966	-.4322	.389						

[a] Volume in board feet, international 1/4-inch scale.
[b] This dbh class was an aggregation of all Grade 2 trees > 15 inches.
[c] This dbh class was an aggregation of all Grade 3 trees > 13 inches.

Discussion

The prediction system described above is intended to provide information for the management of hardwood stands in the minor bottoms of Mississippi. Before the prediction system can be put into operation for a given stand, however, the system requires two additional components: information on the distribution of trees (by species) among 2-inch diameter classes, and a way to estimate individual tree volume. The first component involves the generation of a stand table, something that could be provided from information gathered during a conventional inventory, or predicted by a diameter distribution model. The second component can be furnished best by a local volume model (table or equation) since this type of model requires no information on individual tree height. Even without such local volume information, a type of standard volume equation can be (and has been) generated from the permanent plot database using dbh and the average height of dominant trees within a given stand as independent variables.

Example

A cherrybark oak tree was chosen at random from the data set to illustrate the use of the discriminant functions and the volume distribution equations. The tree had a dbh of 15.0 inches, and the basal area/ac recorded for the plot was 137 ft^2 (derived from the dbh of measured trees on the plot and plot size). Relative basal area therefore was calculated as 0.008957. Substituting these values into the discriminant functions for cherrybark oak in Table 1 yielded:

$$l_1 = 4.89450(15.0) - 2158.85939(.008957) - 32.36441 = 21.72$$
$$l_2 = 4.39703(15.0) - 2088.09963(.008957) - 23.90176 = 23.35$$
$$l_3 = 3.75209(15.0) - 1881.88749(.008957) - 16.55070 = 22.87$$
$$l_5 = 2.64836(15.0) - 1373.58928(.008957) - 8.07015 = 19.35.$$

ee. In this case, the oak is assigned a grade of two.

The next step is to calculate the proportion of total tree volume fall-
g into each log grade. Using equation [3] and the coefficients in Table 2
r tree grade two, we predict

$$
\begin{aligned}
P_2 &= .5586e^{-.7587(2-2)} = .5586 \\
P_3 &= .5586e^{-.7587(3-2)} = .2616 \\
P_4 &= .5586e^{-.7587(4-2)} = .1225 \\
P_5 &= .5586e^{-.7587(5-2)} = .0573
\end{aligned}
$$

, approximately 56, 26, 12 and 6 percent of the tree's total volume will made up of log grades two, three, four, and five, respectively. If the ee contains an estimated 209 bd ft (international, ¼-inch scale), the per- ntages above translate to 117, 54, 25, and 13 bd ft in log grades two rough five. (Volume estimate was made using a standard volume equation rived from the permanent plot data.) Actual volumes for the tree, in bd , were:

Total	Grade two	Grade three	Grade four	Grade five
203	116	78	0	9

This entire process would need to be repeated for every tree in a given and table, or tree list. Although in the above example the prediction stem appears to have done a good job in apportioning volume by log grade, ution should be used in trying to predict such volumes for individual ees. It is expected that volume estimates aggregated to the stand level ll be much more reliable.

Acknowledgments

The establishment and measurement of plots, and the subsequent supple- ntary plots, were made possible through a cooperative agreement with the DA Forest Service, Southern Forest Experiment Station, Southern Hardwood boratory. Approved for publication as Journal Article P-7605 of the Mis- ssippi Agricultural and Forestry Experiment Station.

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TERFACING A REGENERATION MODEL WITH GROWTH AND YIELD MODELS [1]

Dan Dey, Paul S. Johnson, Gene (H.E.) Garrett and Paul L. Speckman [2]

Abstract. The Tobit model was used to predict the height distribution of oaks in 10-year-old even-age oak stands in the Missouri Ozarks from the preharvest size of advance reproduction and site factors. This is a linear regression model designed for use with a limited dependent variable (LDV). Future tree height is a LDV because trees that die within a given growth period are limited to a future height of zero while trees that survive grow to positive heights. In our application, the Tobit model facilitated estimating the probability that a stem of advance reproduction of a given initial size (i.e., before final harvest of the parent stand) on a given site will grow into a given height class ten years after final harvest. The resulting individual-tree probabilities are summed by future height classes across all surviving trees to produce a predicted tenth-year population height distribution. For each stem of reproduction, the Tobit model specifies the segment of the probability field that represents the probability of mortality. Thus, growth and mortality are simultaneously accounted for. The modeling procedure can be extended to generate a tree list that can be used as input into existing growth and yield models.

Introduction

Our inability to predict the rst two decades of stand develment has been a missing link in e growth modeling of even-age rdwood forests. In contrast, ere are numerous models for procting the growth of older stands. r the Central Hardwood Region, the tter models include STEMS, TWIGS d OAKSIM in addition to the trational yield tables. However, ose growth projectors cannot predict the development of stands less than about 20 years of age, which typically have mean diameters of 3 inches or less. Those models also are unable to predict the development of reproduction after final harvest.

Sander et al. (1984) developed a probabilistic regeneration model that provides a simple yes or no answer concerning the adequacy of the regeneration potential of oak stands in the Missouri Ozarks. But because that model does not generate future size distributions of trees (and thus a "tree list"), it cannot be coupled to existing growth and yield models to provide forest managers with stand growth projections that not only extend through an entire rotation but also link one rotation with the next.

The objective of the present study was to develop a regeneration

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[1] Paper presented at Sixth Biennial uthern Silvicultural Research Conrence, Memphis, TN, Oct. 30-Nov. 1990.

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model using methodology that can generate future height and diameter distributions from a preharvest inventory of advance reproduction and the overstory. (The composition and structure of the overstory is a determinant of the potential contribution of stump sprouts to future stocking. This component of the regeneration model is discussed elsewhere.) The resulting diameter distributions are then used to construct a tree list for use as input into a growth and yield model such as TWIGS. To illustrate the methodology, a model for projecting tenth-year height distributions from measurements of advance oak reproduction and site factors is presented.

Study Area

We collected data on the development of hardwood reproduction after the clearcutting of six upland oak-hickory stands on the Mark Twain National Forest in the Missouri Ozarks. These stands covered a wide site quality range (black oak site index 47-80, base age 50), slope aspects and slope positions. Within these stands, diameters of overstory trees [trees $\geq$ 1.6 inches diameter breast height (dbh)] were measured on randomly located 1/5-ac plots. Three 1/250-ac plots were then randomly established within each 1/5-ac plot for measuring advance reproduction. In total, 179 1/250-ac subplots were inventoried in the six stands. These subplots contained 1,198 stems of reproduction of which 441 were oaks. Thirty-four percent of the oak reproduction stems were white oak (*Quercus alba*), 45 percent were black oak (*Q. velutina*), 6 percent were post oak (*Q. stellata*), 9 percent were scarlet oak (*Q. coccinea*), and 6 percent were northern red oak (*Q. rubra*).

Total height and groundline diameter of individual stems of advance reproduction were recorded by species before final harvest. These stems were permanently marked and mapped for future monitoring. On each subplot, slope position and aspect were determined. To characterize slope position from ridgetop to creek bottom, we divided slopes into thirds and classified the location of each subplot as upper, middle or lower slope. Three aspect categories also were defined: north to east ("cool"); south to west ("hot"); and all other ("neutral") aspects. Ten years after harvest, the total height and dbh of each living tree was measured.

Selecting A Model

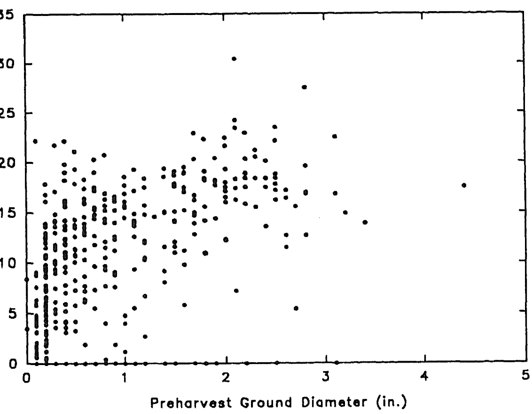
A probability approach to regeneration modeling was used because of the large amount of tree mortality and the rapid and unpredictable changes in the crown class position of trees during the first 20 years of stand development. Sander et al. (1984) took a probabilistic approach to develop the current oak regeneration model that simultaneously predicts tree growth and mortality based on logistic regression. Others have similarly used logistic regression to model forest regeneration (Ferguson 1986, Loftis 1988, Lowell et al. 1987).

To update and expand the utility of the current oak regeneration model,

used a linear regression method commonly known as the Tobit model, which s developed for analyzing data with limited dependent variables (Tobin 58). Since the 1970s, numerous applications of the Tobit model have been ported, primarily in the field of economics (Fair 1978, Keeley et al. 78, Ashenfelter and Ham 1979, Reece 1979, Stephenson and McDonald 1979, ams 1980, Witte 1980, Wiggins 1981).

Limited dependent variables arise when the range of the dependent varble is restricted in some way. Tobin (1958) originated the method to anyze household expenditures on durable goods for a range of income levels using a regression model that specifically took account of the restricon that expenditures (the dependent variable) could not be negative. He ted that the observed relation between household expenditures on a durab good and household incomes contained many observations where expenditure s zero over a wide range of incomes.

That same relation exists between preharvest ground diameters of adnce oak reproduction and height of reproduction 10 years after clearcutng (Fig. 1). The distributional pattern of these data has many of the ne characteristics as Tobin's data. Note the number of observations over range of initial ground diameters where future tree height is zero--ich represent stems of advance oak reproduction that died during the st 10 years after clearcutting. Because tree heights are never negave, we have a dependent variable that is constrained or limited to zero positive values. Hence, future tree height is a limited dependent riable.



gure 1. Relationship between obrved preharvest (initial) ground ameter of advance oak reproducon and total height 10 years af- clearcutting. (Each point reesents 1 to 441 observations.)

In the regeneration stage of stand development, high mortality rates over a range of independent variable values produce numerous observations with zero values of future tree height. This characteristic of the data destroys the linearity assumption so that the least squares method is clearly inappropriate in simultaneously modeling mortality and growth. And using least squares regression on only the survivors fails to account for tree mortality. Tobin (1958) demonstrated that regression based on maximum likelihood estimators is more suitable for modeling when the data are comprised of limited dependent variables.

A Tobit Regeneration Model

Although many Tobit models were nsidered, we found that the "best" one was a 3/2 power transformation of e dependent variable, height at age 10, regressed on the set of indepent variables that included preharvest initial ground diameter, preharvest ight, aspect and slope position. The model is:

$$Ht^{1.5} = 6.1 + 21.5*Di + 5.7*Hi - 1.8*DiHi - 6.0*Aspect1 + 3.2*Aspect2 - 8.5*Slope1 + 5.6*Slope2$$

where Ht = tree height 10 years after harvest (ft),
Di = initial ground diameter for stem i (inches),
Hi = initial total height for stem i (ft),
DiHi = interaction between Di and Hi,
Aspect1 = indicator variable for aspect,
Aspect2 = indicator variable for aspect,
Slope1 = indicator variable for slope position,
Slope2 = indicator variable for slope position,
Std. error = 27.653.

Generating Future Height Distributions

In the ordinary application of regression analysis, we are usually trying to estimate the mean response given some set of initial conditions and thus the regression equation is the final product of our effort. But in the present application, we are more interested in predicting height distributions than in predicting expected future mean heights. This is because of the large variation about the mean for any given initial size and the resulting lack of predictive utility in the mean, per se. In the advance oak reproduction example in Figure 1, the regression line estimates the expected future mean height at age 10 for a given size of advance reproduction. However, a given stem of advance oak reproduction may grow to a larger or smaller height than the future mean height or the stem may die. Thus, in our application we need a model that can estimate the probability of an individual tree growing to a given future height, each of which is distributed about the regression derived mean. At the same time the model must account for mortality.

For the Tobit model, the distribution of all possible future heights about their mean is, by assumption, the normal distribution. Figure 2 illustrates hypothetical normal distributions of future heights about the Tobit regression mean for two different initial ground diameters. The portion of the normal distribution associated with future heights less than zero represents the proportion of advance reproduction of a given initial size that will die during a specified period. Moreover, as initial tree size increases, the area under the normal curve that represents living trees increases and the area representing mortality decreases. This relation is consistent with the general expectation that: (1) the probability of mortality decreases as initial size of advance reproduction increases (Sander 1972); and (2) as a corollary of (1), the probability distribution of the future size of a surviving tree becomes increasingly normal-like as initial reproduction size increases. The latter expectation is paralleled by the increasingly normal-like diameter distributions of populations of surviving trees in even-age stands as stands age and as the probability of individual tree mortality concomitantly decreases (Schnur 1937 and numerous other stand tables).

To generate a predicted future height distribution, the standard normal distribution was used to estimate the probabilities that a given size of advance oak reproduction on a given site will grow into specified future height classes. To do this, we used the original observations on aspect, slope position, and initial ground diameter and height for each of the study trees to generate future height distributions. For each stem of advance reproduction, we computed the mean predicted height at age 10 using the Tobit equation. Then we standardized the distribution of future heights about the regression line using the value of the regression mean and the variance. The standard normal distribution was then segmented into tenth-year height classes. The area under the standard normal curve for each segment of the distribution defined by a given height class thus represents the probability that a stem of advance reproduction of specified initial size on a specified site will grow into that given height class.

This procedure is illustrated in Figure 3 for a simplified, hypothetical regression of future height on initial ground diameter, where a 3-ft height class interval is used to illustrate the division of the normal distribution into segments to facilitate computing the probability of a stem growing into that height class. Note that the portion of the normal distribution lying below a future height of zero represents the probability of mortality. Figure 3 also illustrates the computational process for determining the future height class and mortality probabilities for a single tree. Note that a tree with an initial ground diameter of 0.4 inch will on average grow to a future height of about 3 ft based on the Tobit regression. But in reality, a tree may grow to be any possible future height or it may die. For example, what is the probability that this tree will grow into the 3- to 6-ft height class? To calculate this, we must first determine the probability that it will grow to be less than 3 ft. Then we must calculate the probability that this tree will grow to be less than 6 ft. The result of subtracting these two probabilities is the probability that a tree with a 0.4-inch ground diameter will grow into the 3- to 6-ft height class. This procedure is repeated for each height class. Each study tree is similarly projected and allocated probabilistically to the various height classes. The probability of mortality, the area of the normal curve under the 0 height line, can be ignored because in this application we are only interested in the future height distribution of living trees. However, the area under the entire normal curve, including the mortality sector, sums to 1.0, or 100 percent.

After predicting the future mean height of each of the study trees using the Tobit regression equation and allocating each tree probabilistically to the various height classes, the probabilities are summed by height classes to produce a predicted population height distribution. Summation of the probabilities allocated to that portion of the normal distribution defined by a future height of zero or less would produce an estimate of the number of trees expected to die during the first 10 years after harvest.

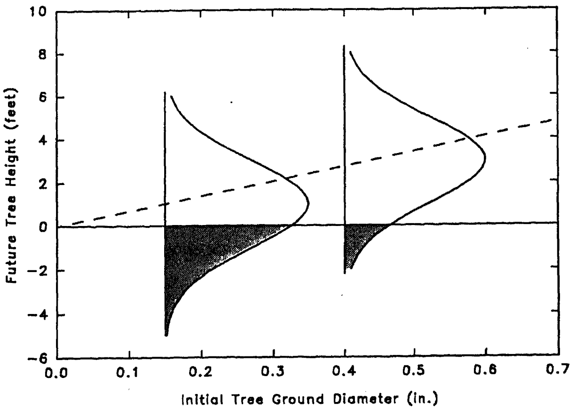


Figure 2. Two hypothetical normal distributions of future tree heights for two initial tree ground diameters, distributed about the Tobit regression mean (—). (The shaded area under each curve is proportionate to the probability of mortality. The remaining area represents the probability distribution of surviving trees in relation to future tree height.)

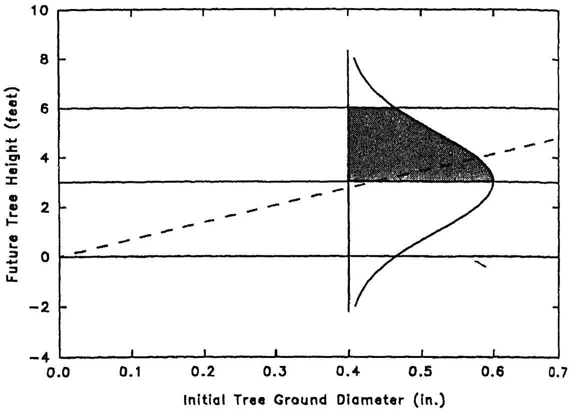


Figure 3. A hypothetical Tobit regression (—) of a future tree height distribution in relation to initial tree ground diameter. (The shaded area under the normal curve is proportionate to the probability that a tree with an initial ground diameter of 0.4 inches will be in the 3- to 6-ft height class at a specified future date.)

Table 1. Comparison of observed and predicted height distributions of oak reproduction 10 years after clearcutting.

Height class	Height distribution Observed	predicted	Calculated chi square	Tabled chi square
(ft)	--- (number of trees) ---			
Mortality	69	71	0.1	
0-6	75	56	0.1	
6-12	106	127	3.5	
12-18	134	128	0.2	
18-24	54	52	0.1	
24-36	3	4	0.8	
Total[1]	441	438	10.7	11.07[2]

[1] The discrepancy between observed and predicted is due to rounding error in the predicted distribution.

[2] For 5 d.f. at 0.95.

Model Validation

Because we did not have an independent data set, we compared the height stribution predicted by the Tobit equation to the observed 10th-year ght distribution of the study trees. Based on chi square, we found that ere was no significant difference between predicted and observed height stributions for 6-ft height classes (α =0.05) (Table 1).

However, selecting the width of height class intervals is arbitrary and affect the outcome of the chi square test. Although we predicted dis- butions using several height class intervals, 6-ft classes produced the t fit to the observed height distribution among those intervals tested.

Conclusion

The Tobit model facilitated generating a future height class distribu- on similar to the observed tenth-year height distribution of oak repro- tion. Because Tobit models can predict both growth and mortality simul- eously, they provide a flexible foundation for generating future height stributions. Our objective is to develop this methodology to generate meter distributions of stands that are approximately 20 years old based preharvest inventories of advance reproduction and overstory trees. The ulting models could thus provide tree lists suitable for input into ex- ing growth and yield models.

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GROWTH AND YIELD COMPARISONS FOR UPLAND OAK STANDS IN THE BOSTON MOUNTAINS OF ARKANSAS [1]

David L. Graney and Paul A. Murphy [2]

Abstract. Equations for basal area growth and total cubic-foot stand volume of even-aged upland oak stands in the Boston Mountains were compared with equations published for stands in the Central States. The basal area growth and stand volume equations for the Boston Mountains were developed using data from 87 stocking plots installed between 1976 and 1981. The same merchantability limits and volume computation procedures used in the Central States were followed in compiling the basal area growth and stand volumes for the Boston Mountains data. Differences were found in the equations for both basal area growth and stand volumes. Divergences in stand volumes were more pronounced when regional taper curves were used to compute tree volumes for the Boston Mountains data. Differences in the data sets with respect to stand age, site quality, and ingrowth and mortality rates may account for the differences. Use of the Boston Mountains equations with stand volumes derived from regional tree-taper curves is recommended when growth and yield estimates are desired for that region.

Introduction

Upland hardwoods (oak-hickory and oak-pine forest types) constitute more than 50 percent of the commercial forest land in the midsouth region. Yet despite this sizable upland hardwood resource, there is no published information on stocking, growth, and yield for midsouth hardwood stands. Schnur's (1937) yield tables, developed from unthinned stands throughout the Eastern United States, have been the main source of information for yield of upland oak stands. Published growth and yield relationships for managed oak stands in the Central States (Dale 1972, Hilt 1985, Shifley 1987) could be valuable to land managers in the midsouth, but it has not been established that growth and yield response to thinning in the Central States is the same for upland hardwood stands in the midsouth. Between 1976 and 1981, the Southern Forest Experiment Station Research Project at Fayetteville, Arkansas, installed a stocking study (Graney 1980) on Ozark National Forest lands in the Boston Mountains of northern Arkansas (Fig. 1). The objective of the study is to evaluate growth and yield response of upland oak stands to thinning.

The objectives of this paper are to: (1) compare basal area growth and stand volume equations developed for upland oak stands in the Boston Mountains of Arkansas with upland oak stand models published for the

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Central States (Dale 1972); and (2) evaluate the use of regional tree-taper equations for determining upland oak stand volumes for the Boston Mountains.

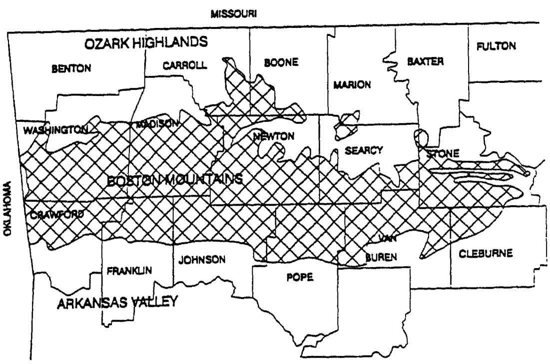


Figure 1. The Boston Mountains of Arkansas.

Study Description

Boston Mountains Study

This study is based on 87 permanent 0.25- to 0.5-ac plots distributed across the Boston Mountains. Stand age at the time of initial thinning varied from 11 to 75 years. Site indexes (Schnur 1937, Farrar 1985) for northern red or black oaks (*Quercus rubra* L. or *Q. velutina* Lam.) ranged from 46 to 82 ft (base age 50). All plots were established in fully stocked, even-aged upland hardwood stands that showed no evidence of recent fire or cutting.

Measurements consisted of a complete inventory of trees larger than 0.5 inches dbh measured to the nearest 0.1 inch. Total height of sample trees, which were selected at random in proportion to the number of stems in each 1-inch dbh class before and after thinning, was obtained for each plot. Four levels of stocking were created by thinning. Residual stands were left with 40, 60, 80, or 100+ percent of full stocking based on Gingrich's (1967) tree-area equation for upland oak stands. Thinning was mostly from below. Culls and poor-quality stems were removed first, then intermediate and suppressed trees of low quality and vigor. High-quality, desirable species were cut only to attain the residual stocking goal and a uniform spatial distribution.

Although 43 tree species are represented on one or more plots, black, northern red, and white (*Q. alba* L.) oaks account for 86 percent of the total basal area over all plots after thinning (Table 1). Plots on site index 50 and 60 are predominantly white oak; those on site index 70 are mixed red and white oak; and those on site index 80 are predominantly red oak (Table 1). Other desirable species such as black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), and black walnut (*Juglans nigra* L.) are present only as scattered individual trees on most plots and account for only about 3 percent of the total basal area. Hickories (*Carya* spp.) and blackgum (*Nyssa sylvatica* March.) plus other species represent 8.5 percent of the total basal area after thinning, but these species are more common in the midstory and understory positions on most plots (Table 1).

Central States Study

Dale's (1972) upland oak equation system was developed from data on 154 permanent-growth plots established as part of eight growth studies representing upland oak stands in Iowa, Kentucky, Missouri, and Ohio. Individual studies were installed between 1949 and 1962 and represented 5 to 12

Table 1. Percentages of numbers of trees and basal areas by site class and species group[1] for Boston Mountain study after first thinning.

Site index	Group 1		Group 2		Group 3		Group 4		Group 5	
	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area	No. trees	Basal area
(ft)	(percent)									
>56	47.3	58.6	19.8	24.4	1.0	0.6	24.3	13.8	7.6	2.6
56-65	41.4	54.0	17.5	30.6	4.7	3.8	18.8	7.0	17.6	4.6
66-75	39.6	45.9	27.0	41.9	3.4	3.2	20.0	7.3	10.0	1.7
75+	28.3	30.3	34.1	58.3	2.6	1.4	15.7	6.9	19.3	3.1
All sites	41.1	47.6	22.2	38.3	3.1	2.5	20.3	8.5	13.3	3.1

[1] Group 1: White oak.
Group 2: Black oak, northern red oak, southern red oak.
Group 3: Ash, basswood, black cherry, black walnut, cucumber tree, shortleaf pine.
Group 4: Beech, blackgum, blackjack oak, black locust, chinkapin oak, elm, hackberry, hickory, post oak, red cedar, sugar maple.
Group 5: Blackhaw, buckeye, devil's walkingstick, dogwood, Indian cherry, hophornbeam, mulberry, Ozark chinkapin, papaw, persimmon, redbud, red haw, sassafras, serviceberry, spice bush, tree huckleberry, umbrella magnolia, wild plum, witch hazel, miscellaneous understory.

years of growth. Initial stand age varied from 22 to 90 years. Site indexes--based on Schnur's (1937) curves for upland oaks--ranged from 55 to 89 ft (base age 50). All plots represented fully stocked, even-aged upland oak stands that showed little evidence of recent fire or logging. Four or more density levels were created by thinning. Cutting varied from very light or none to removing 70 or 80 percent of the original basal area. Stands were thinned to leave a suitable number of the best stems as evenly spaced as possible over the plot. Species composition varies widely among studies, from white oak in the Kentucky studies to almost pure black oak in the two Missouri studies. Over all plots, upland oaks represent at least 90 percent of the total basal area after thinning.

Analysis

For this analysis, some 87 plots were available; 68 plots had two 5-year growth periods, and 19 had one 5-year growth period for a total of 155 growth observations. Plot basal area per acre was calculated for all live trees 2.6 inches dbh or larger for each plot measurement. Net annual basal

area growth for each period was calculated by subtracting the initial basal area from the ending basal area and dividing by the growth period. The average basal area for the growth interval was calculated by averaging the beginning and ending basal areas. Average age was also calculated as the mean for the growth period.

Plot Summary

Several conventions were observed to make the results comparable: (1) the same threshold diameter of 2.6 inches was used; (2) the same definition of tree total ft³ volume was observed; (3) plot height-diameter curves were constructed for the same species groups; and (4) the same total ft³ volume equation was used to calculate tree volumes for plot volume summarization.

Individual tree volumes-- ft³, outside bark, from ground level to tip, excluding branches--were calculated by two different procedures. In one procedure, they were computed from the total ft³ volume equation developed by Dale (1973) to ensure that the results of the Boston Mountain study would be comparable to those for the Central States (Dale 1972). In the second procedure, tree volumes were calculated using individual species tree-taper curves developed by Clark et al. (in press). If a taper equation was not available for a particular species, one for the genus or appropriate species group (for example, the red oak group) was used instead. Lacking this option, volume was calculated using equations developed for soft hardwoods or hard hardwoods as appropriate.

Both techniques required total tree height and diameter. Separate height-diameter curves were constructed for red oaks and white oaks at each plot measurement. Non-oak species were combined with the red oak group.

Plot volumes/ac were determined for each measurement by summing the volumes of all live trees 2.6 inches dbh or larger. Average plot volumes/ac for each growth period were calculated by averaging the beginning and ending volumes. Note that these average volumes include ingrowth and mortality for the period. Plot volumes were summarized for both tree-volume computation procedures.

Mathematical Models

The models (Dale 1972) for basal area growth and average total ft³ volume are, respectively:

$$B_g = -BA^{b_1}\ln(B) + b_2BA^{b_3} + b_4BSA^{b_5} \qquad [1]$$

$$\ln(V) = c_1 + c_2S + c_3\ln(B) + c_4A^{-1}, \qquad [2]$$

where, B_g = net annual basal area growth (ft²/ac) for trees 2.6 inches dbh or larger,

B = average basal area (ft²/ac) in trees 2.6 inches dbh or larger,

A = average stand age in years,
S = site index (ft, base age 50),
V = average total ft^3 volume/ac in trees 2.5 inches dbh or larger,
b_i = coefficients to be estimated for basal area growth equation, and
c_i = coefficients to be estimated for volume equation.

Equations [1] and [2] were solved as a system of equations using nonlinear seemingly unrelated regressions (SAS Institute 1984). This technique does not account for possible serial correlation between growth observations on the same plot; no procedure to account for this potential error structure was available for the analysis. The first fitting used data in which the tree volumes were calculated by Dale's (1973) tree-volume equation. This data set will be called "Boston Mountains-combined species." The second fitting used data in which the tree volumes were calculated using tree-taper equations developed by Clark et al. (in press). This data set will be called "Boston Mountains-individual species."

Results

Table 2 shows the goodness-of-fit statistics for equations [1] and [2]. Note that the coefficients of determination for basal area growth are higher for the regressions of the two Boston Mountains data sets than for the Central States data sets. However, the average annual basal area growth rates for the Boston Mountains and the Central States are virtually identical at about 1.8 ft^2/ac. The coefficients of determination are not markedly different for total stand volume, equation [2], for the three data sets.

Coefficients of determination were also computed for the Boston Mountains-combined species data set using the Central States coefficients. The coefficients of determination are 0.494 for basal area growth and 0.793 for total ft^3 stand volume. These are much poorer than the coefficients of determination for the fitted equations for the Boston Mountains data (Table 2).

The coefficient estimates for the Boston Mountains data sets agree in sign with those for the Central States for both basal area growth and stand volume (Table 3), but there are some divergences in magnitude. Note that the coefficient values for equation (2) differ significantly for the two Boston Mountains' data sets.

Figure 2 compares basal area development of upland oak stands in the Central States with that in the Boston Mountains using regression results from the combined-species data set, which conforms more closely to the Central States data. Note that for the three initial basal areas and the two different site index classes shown, basal area development in the Boston Mountains apparently outpaces that in the Central States for ages 50-60 years. Although the difference in growth for any single year is not great, it increases over time.

Table 2. Goodness-of-fit statistics for basal area growth and total volume equations for Central States and Boston Mountains of Arkansas.

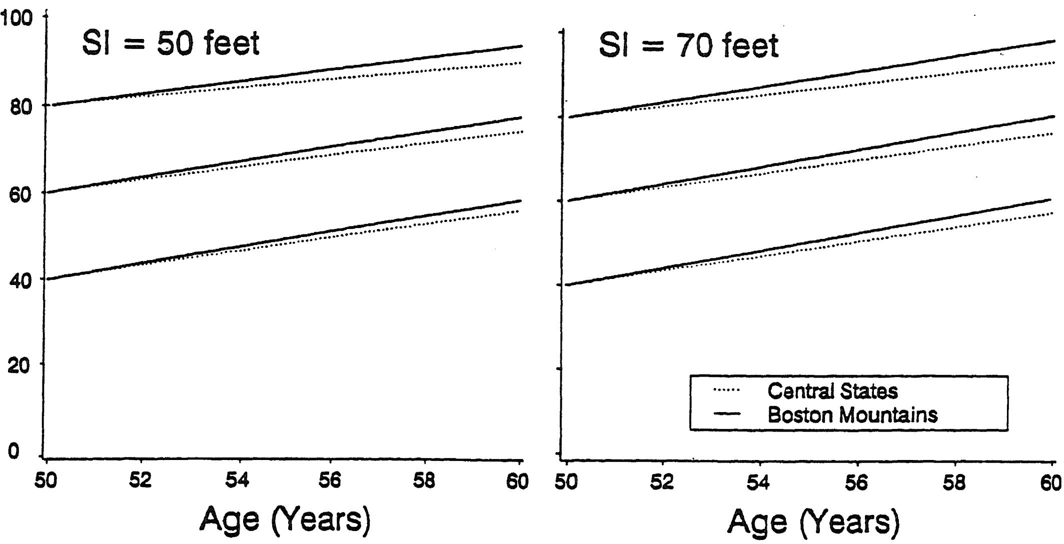
Equation number	Mean of dependent variable	Coefficient of determination	Root mean square error
		Central States*	
(1)	1.80	0.518	0.733
(2)	7.463	.984	.064
		Boston Mountains–combined species	
(1)	1.81	.772	.571
(2)	7.727	.969	.089
		Boston Mountains–individual species	
(1)	1.81	.772	.571
(2)	7.666	.984	.075

* Source: Dale 1972, table 11.

Table 3. Coefficients for basal area growth and total volume equations for Central States and Boston Mountains of Arkansas.

Coefficients	Central States*	Boston Mountains Species: combined	Boston Mountains Species: individual
		Basal area growth	
b_1	-0.8	-0.79510	-0.79521
b_2	3.6852	2.4632	2.4999
b_3	-0.75	-0.64447	-0.64812
b_4	0.011383	0.27849	0.26740
b_5	-1.05	-1.7474	-1.7384
		Total ft^3 volume	
c_1	3.0909	2.8207	3.0749
c_2	0.0093018	0.012765	0.013435
c_3	1.03909	0.97803	0.93645
c_4	-20.110	-5.8054	-14.581

* Source: Dale 1972, table 11.



igure 2. Computed basal area development for even-aged upland oak tands from ages 50-60 years in the Boston Mountains and Central tates, given different initial stand basal areas and site indexes.

sible Explanations for Differences

There are several possible reasons for the differences in predicted ba- area development, one of which is mortality and growth characteristics. e (1973) recorded an average annual ingrowth rate--that is, the ratio of number growing past the 2.6-inch dbh threshold to the average number of es/ac--of 0.0063. The ingrowth rate for the Boston Mountains data was 136, twice as high as that for the Central States. The average annual tality rate--the ratio of the number of trees dying to the average num- of trees--for the Central States data sets was 0.0092, whereas the av- ge for the Boston Mountains was 0.0109. The net annual change in es--ingrowth rate minus the mortality rate--is negative for the Central tes, whereas the net change for the Boston Mountains is positive. This l overall increase in stems might boost basal area growth, albeit very ghtly.

Initial stand characteristics also differ. The average initial ages the Central States data sets ranged from 22-90 years, with a good rep- entation within this range. Ages in the Boston Mountains data set ged from 11-75 years, but nine plots were 11 years old, and the rest ied from 33-75 years. Site indexes for the Central States ranged from 89 ft and averaged 69 ft (calculated by weighting the midpoint of the ges of each data set by the number of plots); site indexes for the Bos- Mountains ranged from 47-82 ft and averaged 64 ft. Overall, site in- es were poorer for the Boston Mountains. Site indexes for the Boston ntains' plots were based on height and age measurements taken from nor- rn red and black oaks; no white oaks were used. Because the site index the northern red and black oak is 3-5 ft higher than for white oak on same location, the Boston Mountains site indexes may be somewhat higher

than equivalent Central States plots if the Boston Mountains site indexes had been based on white oak. This difference might be especially significant, because the b_4 coefficient in equation [1], which showed the greatest difference, acts on a site variable.

Another explanation might be different species mixtures. The Boston Mountains data set has a more tolerant understory--as evidenced by greater percentages of species in groups four and five--than the Central States data sets. The Central States studies were installed in stands that had a short history of fire protection, about 20 to 30 years, and a tolerant understory had not yet developed fully (Dale 1990).

Figure 3 depicts stand development in total cubic volume by site index and stand age over a 10-year period. For site index 50 ft, the three volume estimates diverge appreciably, and this divergence increases with increased initial basal area. The relative ranks of the estimates do not change. When site index is 70 ft, however, Central States volumes are close to those for Boston Mountains-individual species. As initial basal area increases, Central States volumes coincide with those for Boston Mountains-combined species for initial densities of 60 ft^2, and then surpasses both when initial basal area is 80 ft^2. The relative positions of the Boston Mountains estimates do not change, but they do diverge with increasing initial basal area.

Note that the basal area growth equations were used to obtain ft^3 volume development, and that the differences in basal area projections are imbedded in the volume estimates. However, there also seem to be intrinsic differences in the volume estimates. Some of the reasons for differences in basal area estimates can be advanced for volume projections as well. As with basal area, the coefficient for site index in the stand volume equation [2] has more impact for the Boston Mountain data sets than for the Central States (Table 3).

Equation [2] for the Boston Mountains-individual species data set predicts less volume than for Boston Mountains-combined species (Fig. 3). This difference can probably be attributed to the tree-volume computation. Table 4 compares individual tree volumes after the initial thinning calculated by the tree-volume equation with those calculated by the tree-taper curves. The tree-volume equation predicts about 0.4 ft^3/tree more than does the tree-taper equation for all species, and the paired t-test indicates that the volumes are different ($p = 0.0001$). The tree-taper volume estimates are probably more precise because they were developed from a data set that included samples from the Boston Mountains and can account for species differences. Therefore, their use is recommended for the Boston Mountains area.

Conclusions

Despite painstaking efforts to minimize differences in computation procedures, the basal area growth and total stand volume models for the Central States (Dale 1972, 1973) and those for the Boston Mountains-combined species data sets still produced different estimates. Although several plausible reasons can be advanced for these differences, none can be proven

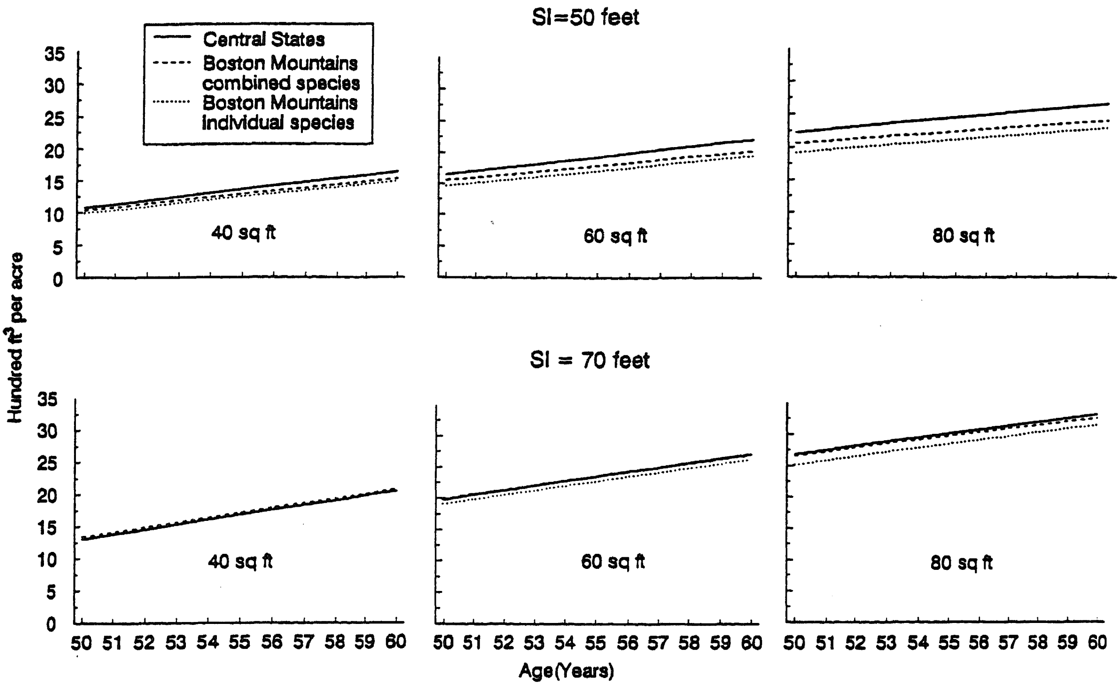


Figure 3. Total volume development for even-aged upland oak stands from ages 50-60 years in the Boston Mountains and Central States, given different initial basal areas and site indexes.

Table 4. Comparison of tree volumes calculated by combined species volume equation versus volumes calculated using individual species tree-taper equations for Boston Mountain study.

Species group [1]	Number of trees	Difference [2]	
		Mean	Standard deviation
		ft³	
1	4,112	0.38	0.21
2	2,712	.20	.54
3	262	.39	.52
4	1,833	.49	.34
5	1,197	.67	.12
All species	9,616	.40	.37

[1] Group identities are the same as those provided in Table 1.

[2] Difference = combined species volume minus tree taper volume.

to be the real cause. Perhaps comparing growth and yield between different studies is inherently hazardous.

If a user wants basal area growth and total volume estimates for even-aged upland oak stands in the Boston Mountains, we recommend using the equations developed from the Boston Mountains-individual species data set (which uses volumes computed from tree-taper curves). The simple two-equation growth and yield system described here does not provide answers to questions of yields for other merchantability limits and volume measures. However, further analysis is being done with the Boston Mountain data, and more comprehensive growth and yield information will be developed.

Acknowledgments

Work was done in cooperation with the Department of Forest Resources and Arkansas Agricultural Experiment Station, University of Arkansas at Monticello.

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GENERATION OF A NEW TYPE OF STOCKING GUIDE THAT REFLECTS STAND GROWTH [1]

J.C.G. Goelz [2]

Abstract. A simple method was developed to prepare stocking guides based on predicted growth. A growth and yield model for southern Appalachian hardwood forests in North Carolina and Georgia was used to generate the stocking guides. Although the stocking guides are presented on the typical axes of basal area versus number of trees, the lines represent predicted growth rather than an arbitrarily defined stocking percentage. The results indicate that stocking guides should vary according to product goals and species composition; the pattern of growth does not change appreciably with site index and age. Guidelines on practical use of the stocking guides are given.

Introduction

The Gingrich (1967) form of stocking guide is very useful when making decisions regarding thinning even-aged stands. The USDA Forest Service (undated) has accepted the Gingrich guide as the standard for stand density management. The basics of the Gingrich guide are: (1) the X-axis is trees per acre; (2) the Y-axis is basal area; (3) the Z-axis is stocking, represented as contour lines of equal stocking. Three contours of stocking are highlighted-- the A-line represents average maximum stocking, the B-line represents minimum stocking for full site utilization, and the C-line represents stands that will achieve the B-line after 10 years of growth on average sites. Stands above or below the A-line should converge toward it. Growth in total volume or basal area should be more or less equal between the A- and B-lines (Gingrich 1967). The choice of residual stocking should be between the A- and B-lines, with the appropriate level determined by product goals.

The Gingrich stocking guide is based on a number of assumptions, some of which were stated by Gingrich, and others that were not. These assumptions are listed below:

1. Stocking is independent of site quality.
2. The stocking guide is independent of stand age.
3. The stocking guide is independent of species composition.
4. Stocking is directly related to growth in volume or value.
5. Stocking guide can be used for a variety of product goals.
6. The stocking guide is independent of stand structure.

If the stocking guide is independent of a given factor, the A- and B-lines should be in the appropriate place regardless of the level of the factor. Leak (1981) found that observed cubic foot volume

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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growth did not relate well to the B-line of the stocking guide for northern hardwoods, upland oaks, and eastern white pine. As growth in total wood or basal area should be constant between the A- and B-lines, the concept of the Gingrich stocking guide is explicitly related to growth. There is a more fundamental implicit relationship between stocking percentage and growth. If stocking, as represented by the distance a given stand is from the B-line, is not related to stand growth, then the guide is useful only as a means to track stand development; it would have no use as a tool to determine appropriate stand density. Furthermore, Leak (1981) found that the inadequacy of the B-line depended on site index and stand age. Leak's findings shed doubt on assumptions 1, 2, and 4.

Chisman and Schumacher (1940), Roach (1977), Tubbs (1977), Stout and Nyland (1986), among others, have observed that species composition must be addressed when determining stocking. This finding invalidates assumption 3.

Growth in total volume or basal area should be relatively constant between the A- and B-lines (Gingrich 1967). However, by changing the product goals, one changes the merchantable volume growth which is proportional to the size of the trees. Thus, for a given number of trees, total cubic foot volume growth may be relatively constant over some range in basal area. However, board foot volume growth will not be constant over this same range. If a stand is located a given distance from the B-line, total cubic foot volume growth will be some proportion of the growth at the B-line. The board foot volume growth will be a different proportion of the growth at the B-line. Thus, the consequence in lost potential growth varies for different products. This fundamental relationship invalidates assumption 5.

Gingrich (1967) observed that stand structure (shape of the diameter distribution) affected stocking only slightly, so he could ignore it for the stands he considered. Thus, assumption 6 is false, but it may not be important for some types of forest.

Leary and Stanfield (1986) and Leary and Stephans (1987) have tried to improve the format of the stocking guide. Leary and Stanfield (1986) observed that the Gingrich stocking guide did not provide information on the future growth of the stand, therefore, they included a direction field that indicates the change in basal area and number of trees over a 10-year period. Thus, Leary and Stanfield's (1986) augmented stocking guide provides information on basal area growth and the trees per acre and basal area of a stand 10 years hence.

Leary and Stephans (1987) attempted to provide a simple way to project stand basal area over time. Because they graphically present all information required to make decisions about stand density over time, their graph is a stocking guide. As in the Gingrich guide, the Y-axis of their graph is basal area. However, the X-axis is stand age and the Z-axis is basal area growth. Leary and Stephans (1987) also superimposed a line that represents the optimal stand density over time and another directional field for basal area growth. Thus, all the elements required for stand density management are presented. The optimal line indicates where a manager would like a stand to be, the Z-axis (presented as a contour plot) provides information on the basal area growth for a given stand, and the direction field indicates how the stand will develop.

In this paper an approach similar to that of Leary and Stephans (1987) is taken, but Gingrich's X-axis = trees per acre is retained. If a combination of basal area and number of trees is a better indication of stand density than basal area alone, or if the size of the tree is more indicative of the capacity to grow than its age (keeping other variables constant), then trees per acre is a more appropriate X-axis. Curtis (1970) indicated that basal area, by itself, is not a good indicator of density. Morris (1948) has shown that size is sometimes more indicative of ontogeny than age.

Here, predicted cubic foot volume growth was chosen as a Z-axis rather than basal area growth as Leary and Stephans (1987) did. A manager is likely to have more interest in volume growth than in basal area growth, because volume is sold, not basal area. Ideally, value growth would be preferred; however, the model utilized here present species groups that each consist of several species of different value. Information was lacking on the typical composition of the species groups and the value of the individual species in the geographic region covered by the model.

In this paper I address assumptions 1 to 5 and present an alternative that does not rely on them. The emphasis is on presenting a way to look at stocking guides, rather than on producing usable stocking guides.

Methods

Predicted cubic foot growth was estimated from the growth and yield model of Bowling et al. (1989). The model, which predicts growth of Appalachian hardwoods in the Blue Ridge physiographic province of North Carolina and Georgia, has a diameter distribution structure that allows five species groups. This structure is relatively simple for a model that considers multiple species and was chosen primarily for that reason. However, the model does have drawbacks. A relatively small data set was used to fit the model, which has not been extensively used and tested. The model is used to represent the true world and the model output is used to assess assumptions 1 to 5. The inferences made in this paper are based on the assumption that the model represents the truth, an assumption that is tenuous for any growth and yield model. It would be equally justifiable to test the reliability of the model by how well it reproduces a stocking guide (Brand and Leary 1988).

Five stocking graphs were produced, based on different stand conditions. The first graph is considered a baseline for comparisons; each of the other four has one stand characteristic that is different from the baseline conditions. The stand conditions for the five graphs (A-E) are listed in Table 1.

Using each of the five conditions listed above, 36 model runs were made by varying basal area and trees/ac. The levels of basal area were 40, 55, 70, 85, 100, and 115 ft^2/ac. The densities were 50, 175, 300, 425, 550, and 675 trees/ac. Some of the combinations of basal area and density gave poor results and were dropped. The program produced errors for stands with large quadratic mean diameters.

able 1. Stand conditions for stocking graphs A through E.

raph	Age	Site index	Top diameter	Species	Basal area	Number of trees
	-yr-		-- inch --		-------- percent	-------
A	30	75	3	Red oak	25	21
				White oak	26	25
				Intolerant	28	24
				Tolerant	12	20
				Misc.	9	10
B	30	90	3	Red oak	25	21
				White oak	26	25
				Intolerant	28	24
				Tolerant	12	20
				Misc.	9	10
C	60	75	3	Red oak	25	21
				White oak	26	25
				Intolerant	28	24
				Tolerant	12	20
				Misc.	9	10
D	30	75	3	Red oak	10	10
				White oak	11	13
				Intolerant	70	60
				Tolerant	5	11
				Misc.	4	6
E	30	75	9	Red oak	25	21
				White oak	26	25
				Intolerant	28	24
				Tolerant	12	20
				Misc.	9	10

The model runs provided 30 to 34 data points for density, basal area, 10-year ft^3 volume growth (X-, Y-, and Z-axis, respectively) for each ph. Rather than plot these raw Z-values, a quadratic function was fit- in trees/ac and basal area to smooth ft^3 volume growth and the smoothed cours were plotted. Other parametric or nonparametric methods could be l to smooth Z over the X-Y axes. The quadratic function was selected use it provides relatively simple surfaces. The true surface is some- : more complex than that represented by a quadratic function. A simple face was chosen because the purpose of this paper is to present ideas, to present a usable stocking guide.

A hand-drawn line was superimposed (although a more formal optimization would be preferred) that represents the basal area at which volume growth is maximized for a given number of trees. This line is the maximum growth line. If the contour surface is an ellipse, the line should represent an axis of the ellipse. The line is an aid in making comparisons among the five graphs. Because the contour surface is a quadratic, the line should be straight. However, the hand-drawn line was placed with respect to the raw data and thus it is not necessarily straight. This line could be interpreted as a thinning decision line when: (1) a stand is much above the line and thinning would probably be beneficial; (2) when a stand is much below the line and thinning would probably be detrimental. When a stand is close to the line, the decision would not be as clear because the decision to thin could have an impact well past the 10-year growth period considered in this study.

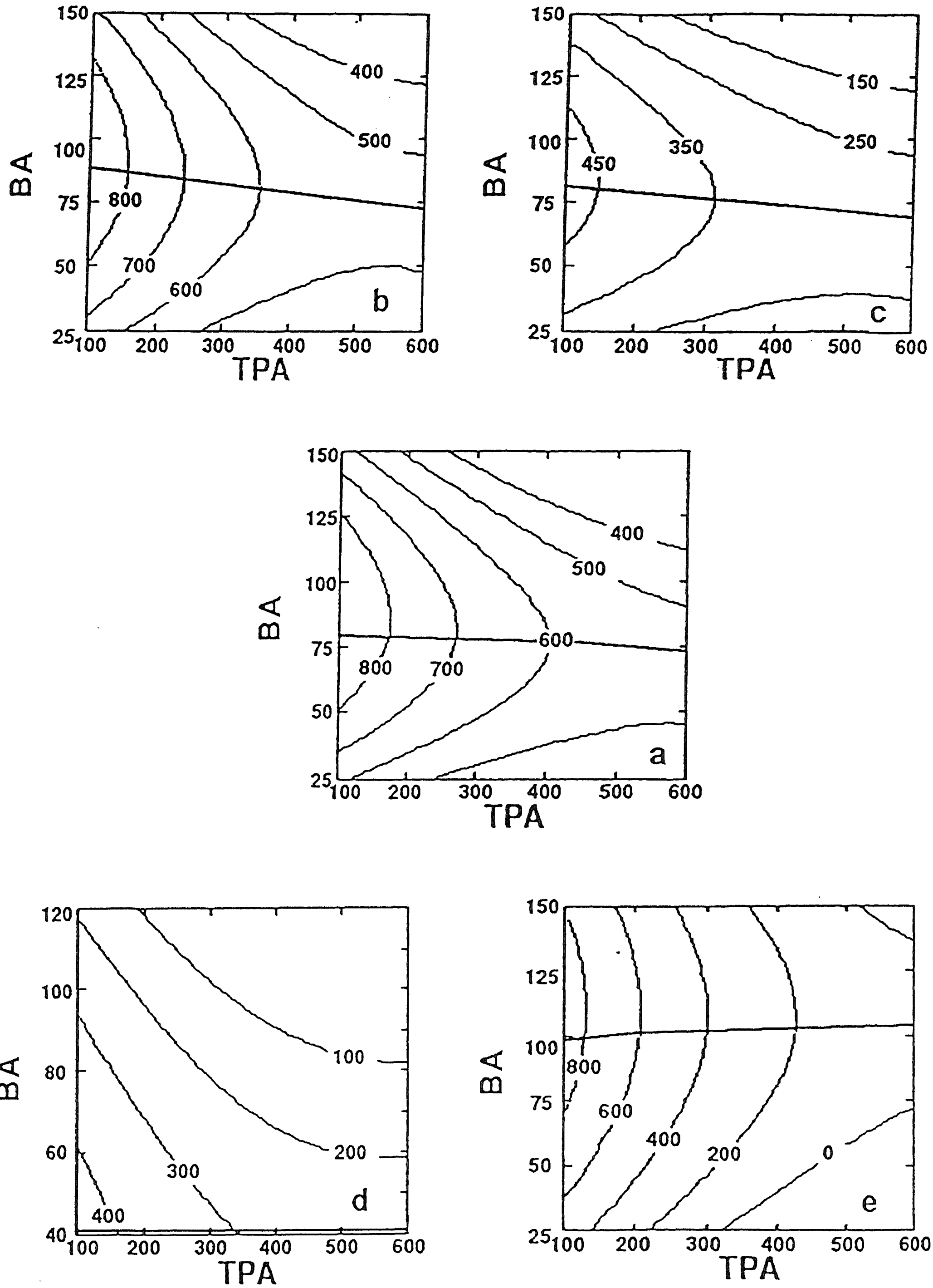
Results

The five stocking graphs are included in Figures 1a to 1e. Figure 1a is the baseline graph. The maximum growth line varies from about 70 ft^2 of basal area in small-diameter stands to about 80 in large-diameter stands. The contours decrease more or less symmetrically from the maximum growth line, as would be expected from a quadratic surface.

As site index is increased (as represented in Fig. 1b), the stocking graph changes very little. The maximum growth line has, perhaps, a slightly greater negative slope than in Figure 1a, but it is in the same general region of basal area. The shape of the contours and even their magnitude is very similar to those in Figure 1a--this result was not expected. Either appropriate residual stocking is insensitive to site index, or the model used does not reflect the real world.

As age is increased from 30 to 60 years, the location of the maximum growth line and the shape of the contours change little (Fig. 1c). The magnitude of the contours does change. Growth is approximately halved by doubling age. However, if relative growth (ft^3 volume growth as a percentage of the maximum growth observed within the ranges of basal area and density) were plotted, Figures 1a, 1b, and 1c would be very similar. This finding indicates that it may be possible to use some standardized measure of growth whereby a stocking guide would be independent of site index and age. Thus, assumptions 1 and 2 could hold for an appropriately developed stocking guide. This potentially important finding should be pursued.

The stocking graph does change dramatically when the proportion of intolerant trees is increased (Fig. 1d). The shape and magnitude of the contours are changed. Although a maximum growth line is indicated, it is placed at the minimum basal area used in the projections. Maximum ft^3 volume growth was greatest at the lowest basal area for all numbers of trees. The magnitude of the differences between Figures 1a and 1d is so large that it might indicate the model is poorly conditioned for extreme values for a given species group. Nonetheless, these results provide additional evidence that it is necessary to incorporate species composition into stocking guides for some types of forest, thus rendering assumption 4 false.



gure 1. Stocking guides for Appalachian hardwoods. Letters a–e corres-
ond to the different stand conditions presented in the Methods section.
e X-axis is trees/ac; Y-axis is basal area in ft²/ac; and the Z-axis is
epresented in contour lines of 10-yr ft³ volume growth/ac. The solid,
re or less horizontal line represents the maximum growth line.

In Figure 1e, the contour lines represent ft^3 volume growth to a 9-inch top rather than a 3-inch top, as in Figure 1a. The contours are approximately the same magnitude as in Figure 1a, but their shape differs. Growth decreases more gradually as basal area diverges from the maximum growth line. Furthermore, the maximum growth line has a positive slope, rather than a negative one as in Figure 1a. The maximum growth line is about 25 ft^2 of basal area higher than the maximum growth line for Figure 1a. This result would imply that assumption 5 is false and that stocking guides are implicitly constructed for a particular product goal.

There are some general results related to all of the guides. The maximum growth line was previously equated to a general thinning decision line. The shape of the contours also reflects the type of thinning to be conducted. A reasonable approach would be to use a method of steepest ascent; that is, to thin a stand such that the volume growth is increased by going uphill perpendicular to the contours. Depending on stand structure, it may be impossible to carry out such a thinning (for example, it may be impossible to decrease density by 200 trees/ac, but only decrease basal area by 5); however, the strategy seems viable when it is possible. As maximum growth is generally at the very low densities, relatively extreme low thinning would maximize growth for most stands. As long as the stand is thinned to (or just below) the maximum growth line, thinning may be reasonable. Some common sense is required, however: the stand should not be thinned so heavily that exposure causes degradation in future log value.

Conclusions And Recommendations

To be meaningful, a stocking guide must be related to stand growth. However, the relationship between stand density and growth should be represented directly, rather than through an index of stocking arbitrarily defined to represent stand density and that need not be related to stand growth. Because a combination of trees per acre and basal area is an effective way to describe stand density for most even-aged stands, all that is required is a way to relate stand growth to trees per acre and basal area. Using the same X- and Y-axes as the Gingrich (1967) stocking guide, a Z-axis of stand growth provides a simple way to directly relate density to growth. Although the ft^3 volume growth is used as a Z-axis, the value growth would more directly address the questions of a land manager. Because this work indicates that the shape of the contour surface is similar regardless of site quality and age, value growth could be transformed or standardized, to provide a guide that is invariant of site quality and stand age. This finding may differ for other growth and yield models. The response surface was very different for different species composition and product goals. Stocking guides need to reflect these factors. A stocking guide could be implemented through a computer program that accepts species composition, product goals, and perhaps other factors, and generates the appropriate guide. A line that represents the solution to the problem of optimal stand density over time would be a useful addition to a stocking guide. This line would be unique for stands of differing site quality.

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AN EXPERT SYSTEM FOR SELECTING AMONG GROWTH AND YIELD MODELS FOR LOBLOLLY PINE PLANTATIONS [1]

Alfredo B. Lorenzo, James E. Hotvedt and Quang V. Cao [2]

Abstract. A prototype of an expert system to select growth and yield models for making stand management decisions in loblolly pine (*Pinus taeda* L.) plantations was developed. The rule-based expert system consists of logical rules reflecting geographical and traditional stand-level information such as stand age, site quality, stand density, and applied cultural treatments to select the appropriate growth and yield model(s). The system is interactive, user-friendly, and requires no prior user-knowledge about growth and yield models. Furthermore, the system is modular and therefore can be easily modified to include more models and rules in its knowledge base and more variables in the data base.

Introduction

Loblolly pine (*Pinus taeda* L.) is currently the most abundant and commercially-favored plantation species in the Southern United States. In the Midsouth alone, the volume of loblolly pine growing stock of 26 percent surpasses that of any other single softwood species (McWilliams and Birdsey 1984). Efficient management of these forests is imperative to guarantee an uninterrupted flow of products from these forest stands. In particular, improving management on these forest stands will require accurate growth and yield information to make sound management decisions concerning stand density, type and intensity of silvicultural treatments, length of cutting cycles, and production goals.

The advent of personal computers during the past decade has allowed foresters to deal with more complex management decisions. The same phenomenon has brought forth the development of computerized growth and yield models for various species or combinations of species. For instance, several models have been developed for much of the natural range of loblolly pine, particularly in the South. Non-exhaustive lists of the more popular growth and yield models developed for loblolly pine along with the characteristics and range of data values used to develop the models can be found in Burkhart et al. (1981) and Dell (1982). Whereas this tends to have increased the array of models available for forest managers to choose from, it has likewise made the task of selecting the right model(s) for various combinations of stand conditions more cumbersome.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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A number of criteria and practical advice for selecting models have en suggested in the literature. Brand and Holdaway (1983) offered model-s a framework for reporting results to better assist users in making eir choice of models. Buchman and Shifley (1983) provided a checklist of antitative and qualitative criteria to use in evaluating and comparing fferent models. Burkhart (1982) suggested specific pointers to look for en selecting growth and yield models. Reports ranging from descriptions selected models to comparative studies between models (Burkhart et al. 81) have also been published. In the context of data and accuracy of ediction, Davis and Johnson (1987) recommended finding answers to these estions to determine the appropriate growth and yield model: (1) Are the mple data used to build the model from the same geographic area and on tes with similar physical characteristics as the subject stands? (2) Is ere documented evidence to the accuracy of the model? (3) And are the dels' structures logical and consistent with the prediction needs and in-ntory data available for the subject stands? Daniels et al. (1979), on e other hand, suggested considering: (1) the reliability of estimates;) the flexibility to reproduce desired management alternatives; (3) the ility to provide sufficient detail; and (4) the efficiency in furnishing e information when selecting among models.

Despite these efforts, there has been no apparent attempt made to stan-rdize, much less to automate, the process of selecting growth and yield dels. In addition, none of these earlier efforts sought to recommend a ngle model for specific stand conditions based on certain known bench-rks. Instead, they have focused primarily on comparing the estimates for e variables including basal area, total volume, and merchantable volume nerated by the individual models.

The number of growth and yield models available to choose from, gether with the number of quantitative and qualitative factors that must considered, suggest that an expert system might be an appropriate tool augment any model selection scheme. Some methodological studies similar nature with the current effort presented in this paper have been ported in areas outside forestry, such as in statistics and operations search/management science (OR/MS). Goul and Tonge (1984) used expert stems to identify the most suitable OR/MS techniques to use under certain nditions. Hand (1984) developed an expert system to choose statistical dels, and guide the user through the use of the selected model.

The objectives of this paper are to: (1) provide an overview of what pert systems are, what their components are, and how they are construc-d; and (2) describe the design and development of a prototype expert stem for selecting growth and yield models for loblolly pine plantations.

Overview of Expert Systems

Expert systems (ES) are among several practical applications that have erged from Artificial Intelligence research. Artificial Intelligence is discipline concerned with developing intelligent computer systems and

machines and understanding how humans think, reason, and learn (Liebowitz 1989). Interest in ES has been around for several years. Nonetheless, ES are variously defined. In this paper, we have adopted Feigenbaum's definition of an expert system as quoted by Harmon and King (1985), that is, "An intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution." Simply stated, ES are designed to emulate the decision-making behavior of a human expert in a restricted domain (Giarratano and Riley 1989). The initial success of ES in the fields of medicine and mining explorations might have generated interests in other sectors including business, geology, engineering, computer science, finance, and natural resources management, including agriculture and forestry (Rauscher 1987). The growing current interests outside the pioneering areas of application might be attributed to the need for handling enormous amount of data and knowledge, the potential of expert systems as a tool for training employees, and the desire for capturing and preserving knowledge and expertise which would be otherwise lost due to personnel changes.

Basic Elements of An Expert System

As shown in Figure 1, a typical expert system consists of: (1) an input/output interface which serves as the communication link between the user and the system where the mode of such an interaction can be menu-driven, graphical, or question-and-answer; (2) a domain, invariant inference engine which controls the search mechanism of the knowledge base by using either a forward chaining or backward chaining strategy or a combination of the two, in an attempt to find a solution; and (3) a domain, specific knowledge base which is the repository of facts and information specific to the problem domain. The knowledge base would include rules describing relations in the domain acquired from the so-called "experts" and other sources. The rules would be representative of the methods, heuristics (knowledge acquired through years of experience and training) and ideas relevant to solving problems in the domain of application.

In an expert system, the knowledge acquired from the "domain experts" and/or literature can be represented by: (1) means of formulas in first-order predicate calculus; (2) use of frames; (3) use of semantic nets; or (4) use of production rules in the form of if-then statements.

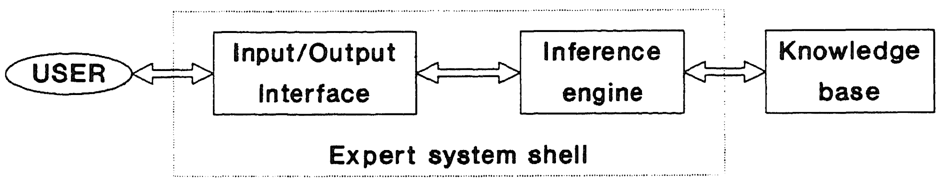

Figure 1. Basic Elements of an Expert System
(Source: Bratko 1986)

nowledge Engineering

Knowledge engineering refers to the general process of building an ex-ert system. The process is basically a three-step procedure. First, a roblem suitable for ES application is selected. In general, problems hich are routinely performed, with at least a willing and articulate ex-ert and with a known solution, are suitable for ES application. Second, he types and sources of knowledge relevant to finding a solution to the roblem are identified and acquired. Third, the knowledge is represented in chosen representation formalism, and then the system prototype is built, ested, and evaluated.

nique Characteristics of Expert Systems

Expert systems are different from conventional computer programs in the ollowing ways: (1) ES are knowledge-driven rather than data-driven and are ommonly non-procedural, hence, more flexible; (2) the knowledge base and nference engine are separate and can be more easily modified incremental-y; and (3) they are highly transparent and capable of explaining and jus-ifying their recommendations.

Basics of Growth And Yield Models

A growth and yield model is a system of mathematical equations for pre-icting stand or tree growth for different combinations of stand and site onditions such as species, age, site quality, and stand density. The rowth component refers to the increase in diameter, height, volume, or ba-al area of individual trees or groups of trees during a specified period. ield, in contrast, is the total amount available for harvest at a given ime (Avery and Burkhart 1983).

Growth and yield models are no longer used solely to predict growth. nformation generated from these models is increasingly being used to: (1) valuate alternative management regimes; (2) determine the type, intensity nd intervals between cultural treatments; (3) determine cutting cycles; nd (4) project inventories used as inputs to harvest scheduling and lanning.

Computer-based growth and yield models can be conveniently classified nto either: (1) whole stand models which provide total volume per acre; 2) diameter distribution models which provide volume by diameter class; or 3) individual tree models which essentially grow each tree in the comput-r. These categories are described and discussed in Munro (1974), Ek and onserud (1979), and Burkhart et al. (1981), to name a few.

An Application in Forestry

This section describes the problem of model selection, the overall tructure and design of the proposed expert system (henceforth called sys-em) for model selection, and the tool used to implement the system. The urpose of the system is to select a growth and yield model appropriate to he conditions of a given loblolly pine plantation from available growth nd yield models.

The Problem of Model Selection

As indicated above, many growth and yield models have been developed for each of the three classifications for different combinations of stand conditions of loblolly pine throughout its natural range. These models vary in the degree of complexity, flexibility, type and minimum inputs required, and amount of detail in the output they provide. Considering the variety of models available, forest managers would benefit from an expert system to assist in determining the right model. The consequences of using an inappropriate model can be serious because important decisions rest on information provided by the selected model. The process of selecting the appropriate models thus becomes a critical consideration.

Model selection can be considered a diagnostic problem. The system performs its diagnosis by asking the user questions about his stand. Then, based on the responses to these questions, the system searches the database for the models appropriate to the conditions of the subject stand.

System Design

The system was constructed with the following considerations in mind: (1) the system should be capable of searching the entire knowledge base efficiently and fast; (2) the system should resemble as close as possible the actual logical thought process that growth and yield model users generally follow; and (3) the knowledge base should be easy to maintain and update. Consequently, much of our efforts were spent on making decisions concerning: (1) the type of knowledge that should be included in the system; (2) the form of representing knowledge internally in the program; (3) the strategy for searching the knowledge base; and (4) the amount of detail in the output.

Knowledge base. The knowledge base of the current prototype consists of facts and information pertaining to the thirteen models shown in Table 1. The data reflect information on physiographic region, site type, method of site preparation, thinning treatment, age, site index, density, and outputs. These variables were selected because they are common descriptors of growth and yield models and are usually known and provided by model developers. Information was obtained from manuals and other publications about the models. This information was coded as "if-then" rules into four functional groups corresponding with the input groups shown in Figure 2. They are: (1) rules for identifying all models that match the conditions of the subject stand with respect to physiographic location, site origin, site preparation, and thinning treatment; (2) rules for selecting models that provide output(s) desired by users; (3) rules for matching available models to the age, site index, and density measures of the subject stand; and (4) rules to rank the models based on overall scores with respect to evaluation criteria.

The models were each evaluated and assigned marks with respect to each of four criteria, namely, simplicity, flexibility, documentation, and auxiliary analysis provided. Scoring was made using a subjective scale of one to ten where one represents the lowest and ten the highest possible performance value that can be attributed to a particular model. The evaluation marks of each model were based on the first author's experiences in using some of the models and what can be inferred from the manuals.

Table 1. Growth and yield models currently in the knowledge base

Model	Type	Physiographic region	Site type	Site prep	Thinning treatment	Age (yrs.)	Site index (feet)	Trees/acre
Burkhart et al., 1972	Whole stand	Piedmont, Coastal Plain	Old-field	None	Unthinned	9-35	47-84	300-2900
Lenhart and Clutter, 1971	Diameter distribution	Piedmont	Old-field	None	Unthinned	9-33	40-80	750-1650
Lenhart, 1972	Diameter distribution	Coastal Plain	Old-field	None	Unthinned	10-30	40-70	500-1200
Goebel and Warner, 1969	Whole stand	Piedmont	Old-field	None	Unthinned	10-25	40-75	500-1400
Feduccia et al., 1979	Diameter distribution	Coastal Plain	Cutover	Burning	Unthinned	3-45	22-78	250-1500
Matney and Sullivan, 1982	Diameter distribution	Coastal Plain	Old-field	None	Thinned, Unthinned	9-34	55-78	484-1742
PCWTHIN (Cao et al., 1982)	Diameter distribution	Piedmont, Coastal Plain	Old-field	None	Thinned	12-30	50-70	355-1305
COYIELD (Amateis et al., 1984)	Diameter distribution	Piedmont, Coastal Plain, Highlands	Cutover	Mech., Chem., Burning	Unthinned	8-25	33.5-97.3	275-950
Smalley and Bailey, 1974	Diameter distribution	Highlands	Old-field	None	Unthinned	10-31	31-89	202-2240
PTAEDA (Daniels and Burkhart, 1975)	Individual tree	Piedmont, Coastal Plain	Old-field, Cutover	None	Unthinned	8-35	47-84	300-2900
PLOB (Baldwin and Feduccia, 1987)	Diameter distribution	Coastal Plain	Cutover	Burning	Thinned, Unthinned	3-45	40-72	100-2700
Hafley, Smith and Buford, 1982	Diameter distribution	Piedmont, Coastal Plain, Highlands	Old-field	None	Unthinned	5-44	48-93	100-2722
Coile and Schumacher, 1964	Whole stand	Piedmont, Coastal Plain	Old-field, Cutover	None	Thinned, Unthinned	5-35	35-80	---

The evaluation criteria relating to simplicity, flexibility, documen-ion, and auxiliary analysis follow: (1) Simplicity relates to how simple is to follow the logic of the model, how much knowledge a user must have understand and use the model, and finally how interactive the model is; Flexibility refers to the ability of the model to calculate required ut data using other available data. For example, if the user is unable provide site index, the model might or might not have the facility to ive it from average height of dominant/codominant trees; (3) Documen-ion refers to how well the manual is written, its readability, and

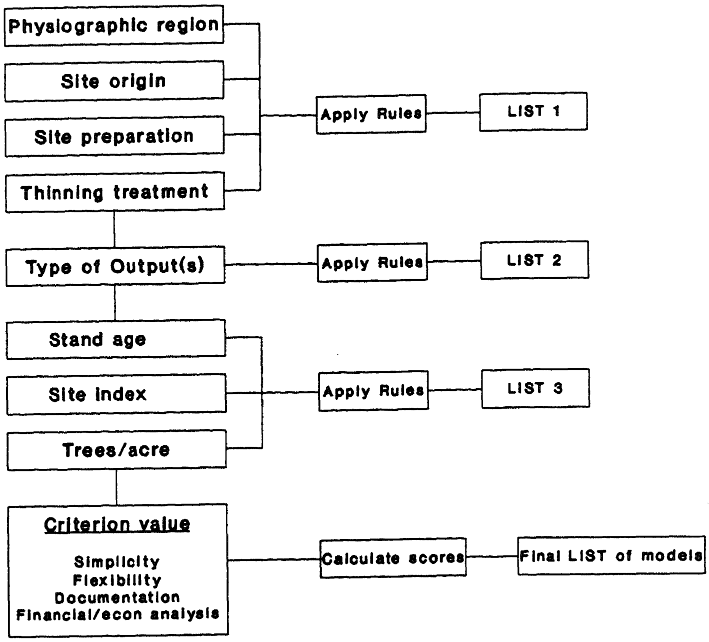

Figure 2. Structure of Proposed Expert System

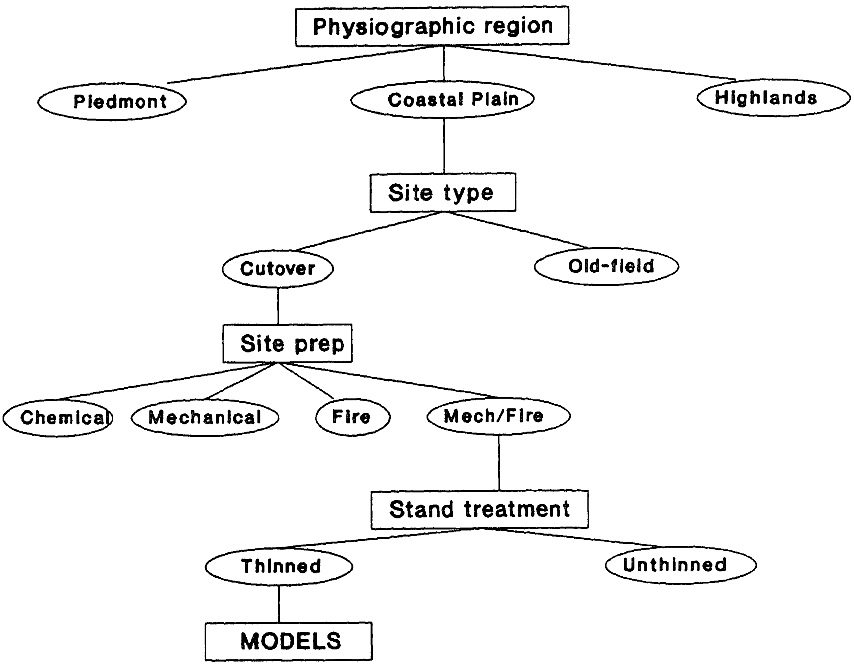

Figure 3. Partial decision tree used in constructing IF-THEN rules.

ount of detailed information describing the use of the model; (4) Auxil-ry analysis pertains to types of analyses other than stand and stock ta-e projection. For example, this might include economic and financial alyses.

Knowledge representation. One of the keys to a successful expert sys-m lies in choosing the appropriate technique for representing domain owledge. The production rules were employed for the proposed changes to stem because they were found to be suitable for problems that can be rep-sented in decision-tree form. A rule has the general form--IF (condition antecedent) THEN (action or consequent) stringed together. For the pro-sed expert system, a typical rule would look as follows: IF Physiograph- region is Piedmont and Site type is Cutover, and Site preparation is escribed burning, and Stand is Unthinned; THEN Model is [...].

Figure 3 shows the possible values of physiographic region, site type, te preparation and thinning treatment. All the potential combinations of e different levels correspond to the first functional group of IF-THEN les in the knowledge base.

Search procedures. A deductive process is carried out using forward aining. Forward chaining is a data-driven strategy for searching the owledge base. The overall search process involves a sequence of exchange information between the user and the system. First, the system requests om the user relevant information about his stand. Second, the system sts a set of models based upon the data given by the user. More specif-ally, the appropriate models are identified in four stages, as suggested Figure 2.

Stage 1. During the first stage, the user is asked questions related his forest stand with respect to: (1) physiographic location (Piedmont, astal Plain, or otherwise); (2) site type (cutover or old-field); (3) inning treatment (thinned or unthinned); and (4) method of site prepar-ion (chemical, mechanical, prescribed burn, combination) if the subject and is site-prepared. The system searches the knowledge base for all dels that match the responses of the user to these questions. Those dels identified form the initial model list, LIST 1.

Stage 2. In stage 2, the user is asked the type of output he would ke to obtain from the model. Models in LIST 1 that fit this criterion e kept in LIST 2. Other models are discarded.

Stage 3. The user is asked about age, density, and site index of his and in stage 3. Models in LIST 2 whose range of data does not include e values entered by the user for age, density, and site index are elim-ated from further consideration. Remaining models form LIST 3.

Stage 4. The user is asked to assign a weight to each of the evalua-on criteria indicating the importance and significance of each criterion the user in stage 4. These weights are multiplied with the corresponding rks arbitrarily assigned by the authors. The products are summed up to tain the overall score for each model remaining after the third stage.

Thus, the composite score for each model is calculated as:

$$S_m = a_m * SIMPLE + b_m * FLEXIBLE + c_m * DOCS + d_m * AUXILIARY$$

where

S_m = total score for model m,
a_m = marks arbitrarily assigned to model m with respect to simplicity,
b_m = marks arbitrarily assigned to model m with respect to flexibility,
c_m = marks arbitrarily assigned to model m with respect to documentation,
d_m = marks arbitrarily assigned to model m with respect to auxiliary analysis, and
SIMPLE, FLEXIBLE, DOCS, AUXILIARY = user-assigned weights.

The overall design of the system described is thus: (1) Generate LIST 1, i.e., all potential models that match user's answers to the initial set of questions; (2) By backward chaining through the knowledge base, LIST 1 is reduced successively to models that provide the kind of outputs the user desires (LIST 2), followed by a reduction of models to those whose range of values for variables age, site index, and density include those of the subject stand (LIST 3); and (3) Models in LIST 3 are shown to the user along with their overall scores with respect to the evaluation criteria. The user indicates his choice (if the default is bypassed) and runs the model if it is available in the user's computer system.

Development Tool

There are two primary approaches to building ES. The first approach is by using a symbolic, non-numeric language like PROLOG or LISP. The second approach is by using an expert system shell which is an expert system without the appropriate knowledge base (Fig. 1). The tool used to develop our proposed system is called KnowledgePro™.

KnowledgePro (Garden, Inc., Nassau, NJ) is an expert system shell that integrates hypertext and expert system concepts for use on personal computers with MS DOS 2.0 or higher and a minimum of 640K RAM. KnowledgePro was selected for its hypertext capability which was used to explain and define terms in the knowledge base as needs arise and for its ability to interface with dBASE, Lotus 123, graphics packages, and user-written Pascal programs.

Limitations and Future Work

Following are some of the apparent limitations of the current prototype: (1) the number of growth and yield models the current system can identify is small compared to the number of available models. For the system to be of practical value, all available models should be included in the knowledge base; (2) the weighting method used is subjective; and (3) the procedures employed in searching for the right models may not be reflective of the logical process experienced model users actually follow in selecting models.

Future work on the system will include: (1) refining the user interface and explanation facility using KnowledgePro's hypertext capability; (2) a major overhaul of the knowledge base to allow for the inclusion of valuable heuristic knowledge from experts and experienced users of growth and yield models; and (3) replacing the weighting method with a more objective, multicriteria evaluation technique.

Conclusions

The ES application presented is in reality a simple one. The same task ould have been easily accomplished from using a simple look-up table simar to the work of Burkhart et al. (1981). On a positive note, the consuction of the prototype has demonstrated the feasibility of using ES chniques for certain trivial activities in forest management. Thus, the tential of ES in forestry must not be overlooked.

Expert systems are slowly finding their way into various aspects of rest management. However, due to their apparent limitations for dealing th dynamic systems they remain outside the mainstream decision-making ols. As a result, they are being widely received with skepticism, parcularly from those entrenched in conventional programming approaches and/ those opposed to innovation. Like any fledgling technology, more quesons and doubts will likely emerge and remain unanswered. One way to rece or eliminate that skepticism is to identify problem areas where ES can applied as a viable alternative analytical tool. Finally, like any new chnique, the successful application of ES in forestry will rely on how tural and easy ES are to understand and how well they blend with existing eory. Whether they will be accepted by those who need to use them will pend on how effective they are in solving problems and on the benefits ined from applying them.

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POLE AVAILABILITY FROM NATURALLY REGENERATED LONGLEAF PINE STANDS: PRELIMINARY DATA [1]

Dennis J. Shaw, Ralph S. Meldahl, John S. Kush, Harold E. Quicke, and Robert M. Farrar, Jr. [2]

Abstract. In 1964, the U.S. Forest Service established a regional longleaf (Pinus palustris Mill.) pine study in the Gulf States. The original objective of the study was to obtain a data base for the development of growth and yield predictions for naturally-regenerated, even-aged longleaf pine stands. The project is now in its fifth remeasurement period (25th-year measurement). Due to the increasing demand for southern pine poles, pole class and length determinations have been added to the study. A summary will be provided of the pole information measured from the 1st year of this fifth remeasurement period. Preliminary data will be presented showing the distribution of poles based on the age, site index, and basal area classes of the study.

Introduction

The range of longleaf (Pinus palustris Mill.) pine extends from southern Virginia to eastern Texas, primarily along the Atlantic and Gulf Coastal Plains with extensions into the Piedmont and Appalachian foothills of northern Alabama and Georgia. It is estimated that longleaf pine forests once covered about 60 million ac of the Southeast. This has decreased to approximately 4 million ac today (Farrar 1990).

From 1964 to 1967, the U.S. Forest Service established a regional longleaf pine study in the Gulf States. The objective of the study was to obtain a data base for the development of growth and yield predictions for naturally regenerated, even-aged longleaf pine stands. Plots were installed to cover a range of ages, densities, and site qualities.

The plots are inventoried on a 5-year cycle and are thinned at each inventory, as needed, to maintain the assigned density level. The study accounts for growth change over time by adding a new set of plots in the youngest age class every 10 years. The project is now in its fifth remeasurement period (25th-year measurement) and the third set of plots was added at the 20th-year measurement. Plans are to carry these three sets of plots to a rotation age of 120 or more years because of increasing interest in the performance of old stands.

Study Details

The study consists of 262 permanent, 1/5-ac and thirteen, 1/10-ac circular net measurement plots. Initial plot selection was based upon a rectangular distribution of four age classes ranging from 20 to 100

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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ears, five 50-year site index classes ranging from 50 to 90 ft, and five esidual basal area classes ranging from 30 to 150 ft^2/ac.

On each plot, all trees with a diameter at breast height (dbh) greater han 0.5 inch are numbered. The following measurements are recorded for ach tree: dbh to the nearest 1/10 inch, azimuth and distance relative to lot center, and crown class. In addition to the regular measurements, tility pole class and length determinations are being assessed for the 5-year and subsequent inventories. A systematic subsample of trees from ach 1-inch dbh class is permanently selected and measured for height to he live crown base, total height, and if the tree is a dominant or co- ominant, for age from seed. A ½-chain isolation strip is maintained round each net plot by thinning it to the same residual basal area level.

Discussion

Southern pines are in increasingly greater demand for use as utility oles. Reasons for this include a large, fast-growing supply, desirable trength characteristics, straightness with a good average taper, and high eceptivity to deep preservative treatment (Williston and Screpetis 1975). hese poles are utilized in carrying electric wires, street lights, and raffic control signals.

Utility poles are classified based on the circumference of the pole at ft from the butt end of the pole. Pole classes range from 1 to 10, the maller the class number the larger the required circumference. For ex- mple, a class-three pole 35 ft in length must be at least 34.0-, but no ore than 41.0-inches in circumference. A class-one pole 85 ft in length ust be at least 55.0-, but no more than 66.0-inches in circumference at 6 t from the butt [American National Standards Institute, Inc. (ANSI), 972].

Selling trees for poles is desirable primarily from an economic stand- oint. Based on information reported in Timber Mart-South, the Alabama tatewide average stumpage price for the first quarter of 1990 for pine oles was $294/MBF (Scribner) compared with $144/MBF for pine sawtimber. rices for product delivered to mill were $339/MBF for pine poles and 239/MBF for pine sawtimber (Timber Mart-South, Inc. 1990).

The main quality that a pole must possess is strength. Most of the ree defects that will keep a tree from being a pole are based on strength onsiderations. The specifications for poles are given in ANSI standards ANSI 1972). The defects that were considered in this study are:

-<u>Crown And Associated Knots.</u> The crown of a tree often limits the ength of a pole because of the presence of large limbs and their assoc- ated knots. Large knots, or a large number of knots create weak points in pole that can cause the pole to break under loads. The allowable number nd size of knots in a given section of pole is determined by the pole lass and length. For example, a class-three pole 35 ft in length cannot ave a single knot larger than 5 inches in diameter and the sum of knot iameters cannot exceed 8 inches in the upper half of the pole.

-Crook. Crook, or an abrupt change in the direction of growth of a tree can limit the length of a pole. For a crook to be allowable, the centerline of the crook section cannot deviate from the centerline of the main pole by more than one-half of the average diameter of the crook section.

-Fork. A fork in the stem of a tree will limit the length of a pole. A large change in diameter of the stem is typically associated with a fork. Forks can also cause the pole to split.

-Limbs And Knots. Some trees will have or have had large limbs low on the bole. These cause large knots which limit the length of a pole as discussed above, under 'crown.'

-Cankers, Scars, Etc. Disease cankers, ligthning scars, and other types of injury to a tree can keep the tree from becoming a pole. These types of scars usually leave dead wood in the tree and leave the tree susceptible to disease and decay. Decay is undesirable in a pole because it creates a weak point, leading to breakage.

-Sweep in One Plane. For poles 50 ft or less, a straight line running from the surface of the pole at groundline to the edge of the top of the pole cannot be distant from its surface at any point by more than 1 inch for each 10 ft of length between these points.

-Sweep in Two Planes. For trees with sweep in two planes (double sweep) or in two directions in one plane (reverse sweep), a straight line from the midpoint at the top of the pole to the midpoint at groundline cannot pass through the surface of the pole.

In the current study, usable pole lengths are measured on all trees 5.2 inches and greater at dbh. Stem taper equations developed by Farrar (1987) are used to calculate the circumference at 6 ft and a computer program developed by Harold Quicke is used to generate appropriate pole classes and lengths. The program generates the largest pole (length and class) that can be cut from a tree. Depending on demand for specific pole sizes, a smaller pole can be produced. Poles that were 25 ft or less in length or that were in classes 9 or 10 were not included because more work is needed in developing taper equations for the smaller trees.

In the current data set, there were 1045 trees that were of pole size. Of this number, there were 235 trees that did not meet pole specifications due to defects, and 104 trees for which there was not a class "fit" because the tree had too large a diameter for its length. For the trees rejected due to defects, the distribution by defect is listed in Table 1.

In this data set, there were no observations in the 20-, 60-, or 120-year age classes. Also, there were no observations in the 50-ft site index class (base age 50), and only a few observations (17 trees) in the 90-ft class. The basal area classes are in feet^2 and all five classes had observations. The distribution of trees and poles by age class, site index class, and assigned residual basal area class are given in Tables 2, 3, and 4, respectively.

Table 1. Defect distribution.

Defect	Number	Percent
Sweep in one plane	83	35.3
Sweep in two planes	74	31.4
Cankers, scars, etc.	26	11.1
Limbs and knots	20	8.5
Crook	19	8.1
Crown	6	2.6
Fork	4	1.7
Diameter change	3	1.3

Table 2. Tree and pole distribution by age class.

Age class	Number trees	Number poles	Percent
40	550	362	65.8
80	414	302	72.9
100	81	42	51.9

Table 3. Tree and pole distribution by site index class.

Site index class	Number trees	Number poles	Percent
60	72	57	79.2
70	424	267	62.9
80	533	371	69.6
90	16	11	68.6

Table 4. Tree and pole distribution by assigned residual basal area class.

Basal area class	Number trees	Number poles	Percent
30	114	87	76.3
60	205	135	65.9
90	252	182	72.2
120	396	244	61.6
150	78	58	74.3

Conclusions

In the 1st year's data, 1045 trees were of pole size. Of this number, 706 (67.6 percent) qualified as poles. Longleaf pine is the preferred species of the southern pines for utility poles because it grows straighter and has a higher percentage of trees that will make poles. The percentage can be as high as 75 percent of the final crop trees in a stand that has been conditioned for poles (Williston and Screpetis 1975). Poles are best grown in even-aged, well-stocked stands because dense stands will have more trees per acre and more trees that will meet taper requirements (Williston and Screpetis 1975). As the plots in this study require thinning, trees that are suppressed, diseased, or otherwise not expected to live for the next 5 years are removed, leaving the healthier, better quality trees. However, the basal area constraints prevent all undesirable trees from being removed, resulting in a lower pole availability.

From the preliminary data, pole availability appears to increase with increasing age to some point, then begins to decrease. This would be an expected trend as trees reach maturity then grow out of pole classes because there is not sufficient height growth to go along with diameter growth. Future plans include looking at points at which trees grow into and out of pole classes. For example, a class-one, 70-ft pole must have a minimum circumference at 6 ft of 51.0 inches, and the maximum circumference that it can have is 61.0 inches (ANSI 1972). Other plans include further work with taper equations, especially on smaller trees and pole classes.

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OVER FIFTY YEARS OF LOBLOLLY PINE GROWTH ON THE CLEMSON EXPERIMENTAL FOREST [1]

Larry E. Nix, Tom F. Ruckelshaus and Arthur T. Shearin [2]

Abstract. Growth and yield results at age 50 of a 35-year, long-term thinning study of old-field loblolly pine (Pinus taeda L.) plantation study plots are presented. A series of plots were installed in stands planted in the late thirties on the Clemson Experimental Forest, located in the Piedmont of South Carolina. Plots were thinned from below to varying levels of residual basal area at 5- to 8-year intervals. Growth and yield in cords and board foot volume are presented. The effect of thinning on tree taper as measured by Girard form class is described. The apparent lack of diameter growth response to thinning as the stands aged is presented with discussion of possible causative factors.

Introduction

The Clemson Experimental Forest s comprised of lands acquired by ne Federal government as submarinal farmland during the "New Deal" ra of the Roosevelt Administration, rom 1934-1939. These lands, orignally some 27 thousand ac, were argely abandoned, eroded farms nose owners had relocated to improve their standard of living. Approximately 3,500 ac of loblolly ine (Pinus taeda L.) plantations ere established on these lands uner the Works Progress Administraion in the late 1930s. In 1939 lemson University began supervising ne management of these lands under n agreement with the Federal govrnment, and in 1954 the land was deeded to Clemson and soon became part of the Clemson Experimental Forest. At about this time, thinning of the loblolly stands was implemented by the research forester, Mr. N. B. Goebel, who set up a series of thinning study plots of varying residual basal areas in order to examine the effects of thinning on the growth and yield of loblolly pine in the upper Piedmont. Of the 32 original plots, 22 remain intact, but only 15 are statistically comparable, i.e., are grouped as plots with different levels of thinning on the same sites with an unthinned control plot. Many of these loblolly stands suffered from severe ice storms in 1945-46 and several less-intense ice storms, windstorms, and the southern pine bark beetles (Dendroctonus frontalis Zim.) in the 1960s and 1970s. Continued urban development in the Clemson area destroyed some of the plot groups and the filling of the Lake Hartwell reservoir obliterated almost all of the few remaining fertile bottomland plots. Viewing black and white photographs taken of the land in the 1930s and comparing them with the current beauty and productivity of

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Paper presented at Sixth Biennial outhern Silvicultural Research Conerence, Memphis, TN, Oct. 30-Nov. , 1990.

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the Clemson Experimental Forest gives one a great sense of appreciation for the faith, wisdom, and foresight of the early conservation foresters of the Depression era.

Because loblolly pine is not indigenous to the upper Piedmont of South Carolina, these early plantations provide a unique opportunity to assess the potential of thousands of acres of such plantings on eroded farmlands of the Piedmont region. A long-term study of thinning in such stands should yield valuable information for many landowners interested in managing their stands for larger, more valuable products on a long rotation. A series of publications have described these study plots (Goebel et al., 1974; Shearin et al., 1985; Nix et al., 1987) and the stands which surround them (Reamer 1981, Holsten and Reamer 1983). The current report is a continuation of this series in hopes of providing further useful information for those interested in managing old-field loblolly pine plantations past chip-and-saw product rotations.

Materials And Methods

In 1953 thinning study plots ranging in size from 0.1 to 0.6 ac with half-chain buffers were established in loblolly pine stands planted in the late 1930s on the Clemson Experimental Forest in the upper Piedmont. The stands were hand-planted at 6 x 6, 6 x 7, and 6 x 8 ft spacing on rolling topography, well-drained, Cecil-Madison sandy clay loam soils in various stages of erosion ranging in site index (base age 50 years) from 76 to 103 ft. At about age 15, low thinnings were initiated on these plots ranging in specified residual basal area from 75 to 135 ft^2/ac. An unthinned control plot was usually left adjacent for comparison. These plots are 50 years old and have been thinned five to seven times at 5-8 year intervals or as basal area growth exceeded the specified residual by 25 ft^2/ac. Residual basal area stocking levels were not replicated at all plot group locations, and the loss of many plots through previously described attrition has resulted in having to group thinning treatments into low (75-85 ft^2/ac), medium (90-100 ft^2/ac), and high (110-135 ft^2/ac) basal area residual levels. In addition, these levels of thinning are no longer replicated fully across similar site indices, which now range from 72 to 98 (base age 50 years), necessitating treating site index as a covariate in comparing thinning treatment levels (specified residual basal area/ac). Although undesirable, such maladies often befall long-term forest studies.

Diameter at breast height (dbh) of all trees on each plot was measured ($\pm$ 0.1 inch) with a steel tape at the permanently marked height of 4.5 ft. Total height of each tree was estimated with an optical clinometer. Stem taper of each tree was measured with a tripod-mounted optical dendrometer equipped with a clinometer. Taper measurements consisted of determining the height ($\pm$ 1.0 ft) to each 1-inch decrement ($\pm$ 0.1 inch) in stem diameter from the dbh. Board foot and cord volumes were calculated using the diameter and total height based equations of USDA Forest Service (1929). Girard form class of each diameter class was determined by interpolation of stem taper curves. Site index of each plot was determined from clinometer measurements of total height of the dominant and codominant trees (nearly

all trees remaining on plots). Diameter and volume values were compared on a plot by plot basis to those simulated with the Piedmont loblolly pine thinning growth and yield model, PCWTHIN (Cao et al., 1982). This was done using as closely as possible the same site index, initial stocking, thinning method, and timing and intensity as were employed on the actual study plots. Statistical comparisons were made using the general linear model procedure and paired t-test of SAS (1985) treating site index as a covariate.

Results And Discussion

Residual and thinning volumes per acre and individual tree parameters at age 50 are compared among four broad levels of thinning in Table 1. Although the residual volumes per acre appear to differ substantially, especially those of the medium (90-100 ft^2/ac) and high (110-135 ft^2/ac) residual basal area treatments, statistical comparisons showed no significant differences even when thinning yields were considered. Although site index differed substantially among the treatment plots, ranging from 72 to 98 ft, it was not a significant covariate in the statistical analysis employed. This is puzzling, as the mean site index values for the treatment levels were 89, 92, 83, and 84 ft for the low, medium and high basal area, and unthinned plots, respectively. Also, on the lower site index plots, the trees of unthinned controls exhibited a substantially lower height growth at age 50 than did those of the adjacent, thinned plots, i.e., the height difference ranged from 6 ft in one location to as much as 18 ft in another. This differnce in height suggests that loblolly, like slash pine (*P. elliotti* Engelm), is sensitive to extreme stocking levels, especially on medium to poor sites. The trees of the unthinned plot on a very good site (SI_{50} = 97) exhibited no reduction in height growth due to crowding and were, in fact, a foot taller than those on the adjacent plots.

Mean volume per tree differed significantly among thinning treatments, with the tree size of the low and medium residual basal area plots being much greater than that of the high basal area and unthinned plots. The lack of mortality in the unthinned plots and the poor diameter growth in the high basal area plots contributed to the differences in average diameter and mean tree volume, but the retention of a high number of trees per acre (nearly twice as many) and the age of the plots apparently increased bd ft volumes in the unthinned plots enough to approach the volumes of the thinned plots (Table 2).

Girard form class values did not differ among treatments nor between thinned and unthinned plots (Tables 1 and 2) as was noted at age 47 in an earlier report (Nix et al., 1987). An examination of tree length stem taper revealed little difference among treatments, except that trees of the low and medium basal area plots had less taper in the lower bole, but more taper in the upper bole than did those of the high basal area and control plots (Nix and Ruckelshaus 1991).

Computer growth and yield simulations with PCWTHIN software, using the same input variables as occurred on the actual plots over the 35 years of

Table 1. Mean volumes and form class values at age 50 for thinned and unthinned old field, loblolly plantations in the South Carolina Piedmont.

Residual basal area	Girard form class[1]	Volume per tree	Residual volume per ac	Thinning yield per ac
(ft^2/ac)		--- (bf-Int 1/8)[2] ---		(cd/bf-Int 1/8)[3]
150-200	80.1	133a	19,004a	0
75-85	81.4	208b	18,394a	28.0/1,328
90-100	81.5	226b	22,074a	25.2/2,333
110-135	80.5	129a	18,356a	29.2/2,148

[1] Girard form class is a ratio of the upper diameter to a lower diameter of the butt log of the tree expressed as a percentile.

[2] Volumes are for trees $\geq$ 9.6-inch dbh (sawtimber size) at age 50 years. Values with the same letter adjacent are not different at the 5-percent level using site index as covariate.

[3] Unthinned plots averaged 24 cd/ac of residual pulpwood (4.5 inch $<$ dbh $<$ 9.6 inch), thinned plots averaged 3 cd/ac.

Table 2. Mean volume and stand attributes for thinned and unthinned old-field, loblolly plantations at age 50 in the South Carolina Piedmont.

Total sawtimber volume per ac	Dbh[1]	Girard form class	Residual basal area	Tree volume
(bf-Int 1/8)	(inch)		(ft^2/ac)	(bf-Int 1/8)
Thinned				
21,544	12.6(12.0)	81.1	95	188
Unthinned				
19,004	10.6(9.8)	80.1	175	133

[1] Trees $>$ 9.5 inches dbh (mean for all trees in parenthesis).

thinnings, revealed significant differences only in the yields for low and medium stocking levels computed from the two data bases. However, volumes predicted differed by over 6,000 bd ft/ac for high stocking plots (110-135 ft^2/ac). An explanation of the lack of statistical significance in such large differences is that the actual study plot volumes vary so greatly because of the unexpectedly poor diameter growth on some plots. Unthinned volume predictions did not differ from the actuals. Mean tree diameters differed significantly between actual thinned plots and computer-simulated thinned plots (Table 3), whereas residual number of trees per acre did not differ significantly even between the simulated and actual high residual basal area plots. The difference in predicted mean dbh and actual dbh was substantial across all thinning levels, ranging from 2.7 inches at the medium basal area residual to 4.1 inches at the low basal area residual (Table 3).

Table 3. Actual and simulated final stand diameters and densities in thinned, 50-year-old loblolly pine plantations in the South Carolina Piedmont.[1]

	Mean dbh residual basal area			Mean density residual basal area		
	75-85	90-100	110-135	75-85	90-100	110-135
	(inch)			(trees/ac)		
Actual	13.0a[2]	13.5a	10.5a	98a	92a	168a
Simulated	17.1b	16.2b	13.9a	64a	84a	119a

[1] Simulations were done with PCWTHIN, an old-field plantation, Piedmont loblolly pine growth and yield model by Cao et al. (1982).

[2] Values in the same column followed by the same letter are not significantly different at the 0.05 level of probability.

Residual dbh values of PCWTHIN-simulated plots were all significantly different even though site index was not a significant covariate in the analysis. Simulated volumes differed by as much as 7,500 bd ft/ac between unthinned and high residual basal area plots and site index was a significant covariate in the analysis. Even if PCWTHIN overestimates yield, comparisons of actual with simulated thinning responses clearly indicate a discrepancy in diameter growth on some of the study plots that is not explained by differences in site quality as measured by site index. For example, one study plot in the high residual basal area group with a site index of 84 has an average dbh of 10.2 inches and a total volume of 13,120 bd ft/ac, while its PCWTHIN-simulated values are 14.7 inches dbh with 23,223 bd ft/ac. There is obviously something wrong with the trees on the actual plot. Extremely poor root development is apparent on some of the plots.

Observations of windthrown trees with very shallow root systems indicate very little vertical exploitation of the thin topsoils that overlay an almost impenetrable clay subsoil. It is probable that as these trees have aged their shallow root systems have extended laterally to the biological limits of their capability in order to supply the ever-expanding crowns which have been given ample room to develop by thinning. Height growth which has slowed significantly only in the past 10 years and is high on the priority scale in tree growth has continued relatively unabated except on the high density plots of the medium to poor sites. Thus, height growth as an early indicator of long-term site productivity may be a poor choice as the key variable in a thinning response growth and yield model for many such old-field plantations or, for that matter, for the second-growth, cut-over plantations of the future. Perhaps soil-site equations need to be developed that can better predict true long-term growth response to thinning of such stands.

Acknowledgments

The authors wish to express appreciation for the able assistance of Doug Benson, Research Forester, Jon Barry, Graduate Assistant, and Jeffry Weyers, former undergraduate, Department of Forest Resources, Clemson University, in the collection of field data.

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INVESTIGATION OF GROWTH 14 YEARS AFTER GLAZE DAMAGE IN A LOBLOLLY PINE PLANTATION [1]

Suzanne Wiley and Boris Zeide [2]

Abstract. Forest management in the southern United States is often complicated by severe ice storms. A heavy accumulation of glaze on needles and branches frequently results in decreased growing stock and a reduced increment for remaining crown-damaged trees. Repeated measurements have provided information on the long-term effects of glaze in a loblolly pine (*Pinus taeda* L.) plantation in southeastern Arkansas. The analysis of growth data from damaged and undamaged trees collected during the 14 years following a severe ice storm reveals that although damaged trees have recovered in height, they are still characterized by slightly lower diameters and volumes than undamaged trees. Annual height growth of damaged trees was significantly greater than that of undamaged trees during the 3-year period following the storm. Height recovery was retarded by stand density. However, diameter recovery was slowest in heavily thinned plots. The diameter increment of damaged trees was reduced during the first 8 years after the storm, but was almost equal to or greater than that of undamaged trees at all but the lowest density during the following 6 years. A period of drought more severely affected diameter growth of damaged than undamaged trees. Forest management in the South should include a thorough understanding of the dynamics of growth recovery after glaze damage.

Introduction

Glaze damage presents a major risk to southern pines in a large portion of the southeastern United States (Van Lear and Saucier 1973). The occurrence and severity of ice storms are unpredictable. The belt of greatest severity and frequency extends from north-central Texas to southern New England. Ice 0.25 to 0.50 inch in radial thickness on needles, branches, and utility w may be expected once every 3 y somewhere in this belt. Nearly of the country east of the R Mountains (except the southern of Louisiana, Mississippi, Alab Georgia, South Carolina, and al Florida) can expect such thickne to occur once in 6 years. Depo of one radial inch or more have recorded in most of this area an the Louisiana coast (Bennett, 19 This unpredictable threat to, li ally, life and limb can reap h in southern pine forests. Coo al. (1971) reported that an storm in South Carolina in 1969 an estimated 60 million dol worth of damage based on the v of wood delivered to mills.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Although the immediate results of these storms have often been reported (McKellar 1942, Brender and Romancier 1960, Kyle 1960, Daley 1964, Goebel and Deitschman 1967, Shepard 1978, 1981, Fountain and Burnett 1979), few data have been accumulated on the long-term effects of glaze damage. A knowledge of the relationship between stand density and resistance to crown damage, and an understanding of the consequences of crown damage on future growth can provide the basis for both immediate and long-term silvicultural decisions.

Loblolly pine (Pinus taeda L.), along with several other pine species, represents a major source of biomass production in the Southeastern Region. Misjudgments in management can easily be made, on one hand, when glaze damage is totally disregarded, or on the other hand, when the seeming disaster immediately following a severe storm results in the unnecessary salvage of the entire stand. The amount of volume lost to natural disasters, such as ice storms, is poorly understood. Quantification of actual growth loss and recovery is needed to make rational management decisions when determining the fate of a damaged stand.

Study Area

In January 1974 an ice storm caused severe damage to much of southeast Arkansas. Burton (1981) carefully documented this damage in forty experimental plots that had been established in 1970 by the Southern Forest Experiment Station in a typical 12-year-old loblolly pine plantation (Burton 1968, 1971). The study was designed to evaluate the effects of four levels of thinning and three levels of pruning on volume growth. Each combination has three replications within a randomized, complete block design. Each plot has a gross size of 132 by 132 ft and contains an inner plot 66 by 66 ft where all trees are individually identified and measured. Plots were initially thinned at age 12 to 40, 60, 80, and 100 ft^2/ac of basal area (BA). Crowns were pruned to 25, 40, and 55 percent of the total tree height (heavy, medium, and light pruning levels, respectively). After the second inventory at age 15, basal areas were reduced to 30, 50, 70, and 90 ft^2/ac, where they have been maintained by subsequent thinnings at ages 24, 27 and 30. Trees were pruned only twice, at age 12 and 15. The seventh remeasurement of the 30-year-old trees was completed in 1987 (Wiley and Zeide 1989, 1990).

Burtons' records and the seven inventories allow us to evaluate the impact of glaze on volume growth in these study plots. The analysis of growth data from damaged and undamaged trees during the 14 years following the storm provides insight into the effects of glaze damage on diameter, height, and volume growth. Because this study includes plots maintained at various thinning levels, the subsequent growth and recovery of these trees can be evaluated in relation to density. Results provided by this study will allow forest managers to assess the effects of glaze damage in terms of growth recovery rather than stand loss.

Methods

In order to evaluate growth after the storm, trees damaged at age which were still present at age 30 are compared with a group of undamag trees with the same mean diameter (dbh) when the storm occurred. Undamag trees which had a diameter below the minimum or above the maximum diamet of damaged trees were not included in the analysis. Trees which were da aged during a second ice storm in 1979 were not included. Three plots we also deleted from the analysis because they were so heavily damaged duri the 1974 storm that their stand density was reduced far below treatme levels. The number of trees present at age 30 for which data were avai able for density levels 30, 50, 70, and 90 (BA) was 3, 5, 11, and 21, re pectively, for damaged samples and 8, 13, 28, and 60 for undamaged sample Diameter, height, and volume (in ft^3 outside bark to a top diameter of inch) were analyzed during one 3-year period before the storm, and fo periods encompassing 14 years following the storm. The periodic annual i crement of diameter, height, and volume, and its standard error was dete mined for each damaged and undamaged sample at each density level. A co rected periodic increment ratio, representing the ratio of annual growth damaged to undamaged trees with an adjustment for any difference in grow between the two groups during the 3-year period before the storm, was ca culated to illustrate actual differences between the growth of damaged a undamaged samples.

The immediate and long-term effects of glaze damage on diamete height, and volume growth were assessed. Growth recovery was quantified terms of the number of years it takes these trees to recoup lost volume d to glaze damage. Since many of the poorer trees were cut during selecti thinnings in 1981 and 1985, these data represent the growth of the "bes damaged and undamaged trees.

Results

Immediate Effects of Glaze Damage

In January of 1974, as the trees reached their 16th year, an ice sto caused severe damage to this test and much of the surrounding area (Fi 1). Burton (1981) reported that 375 (56 percent) of the 668 trees in e perimental plots were damaged. Trees with greater than 50 percent loss the live crown or with the bole bent or butt deflected greater than 45 d grees from the vertical were considered severely damaged and were mark for salvage. Fifty-five percent (208) of the 375 injured trees were c immediately; of these, 85 percent were crown-damaged and 15 percent we root-sprung or bent. The remaining glaze-damaged trees (those which su fered less than 51 percent crown loss and a few with stems bent less th 45 degrees) comprised 36 percent of the test (167 of 460 total remaini trees).

Burton (1981) reported that the thinning and pruning regimes practic in this study significantly affected the amount of glaze damage incurr (Table 1). A substantial majority of crown damage from this storm w caused by stem breakage, within or immediately below the live crown. Me stem diameter at the break was 3 inches. Crown loss was significant

ure 1. Effects of January 1974 storm on 16-year-old trees in a n density plot (thinned to 90 BA pruned to 25 percent of total e height).

greater in trees at all thinning levels which were heavily pruned (to 25 percent of total tree height). The percent of basal area lost was significantly less in heavily thinned plots (30 BA). In plots lightly thinned (to 70 or 90 ft²/ac) and heavily pruned (to 25 percent of total tree height), 50 to 60 percent of the stand basal area was lost. Although dense stands suffered the highest percentage of loss, they contained the most growing stock after the storm. Stand density after the storm was significantly different at all thinning levels (pruning treatments combined) and at all pruning levels (thinning treatments combined). Plots which had been thinned to 90 ft²/ac BA contained twice as much basal area and nearly three times as many trees per acre after the ice storm than plots thinned to 30 ft².

able 1. Percent of basal area in severely damaged trees.

runing level	Thinning level (ft²/ac BA)[1]				Means
	30	50	70	90	
ercent total height)					
LC[1]25	28	39	50	60	44 b
LC 40	3	24	20	36	21 a
LC 55	8	9	18	18	13 a
Means	13 a	24 b	29 bc	38 c	

BA = basal area in ft²/ac; LC = live crown as a percentage of total tree height. Means with the same letter are not significantly different at the 0.05 level (after Burton 1981).

g-term Effects of Glaze Damage on Tree Growth

Diameter growth. An analysis of diameter data (at dbh) collected at 12, 16 (immediately following the storm), 19, 24, 27 and 30 years of

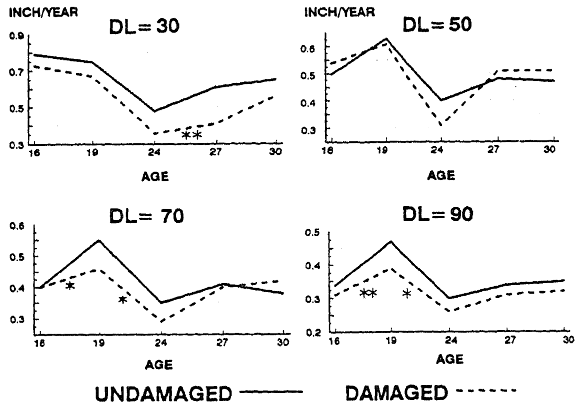


Figure 2. Effect of glaze damage on subsequent diameter increment of damaged trees under four thinning regimes. [DL = density level in ft²/ac BA. Mean diameters of damaged and undamaged samples at age 16 are equal. ** = significantly different from undamaged trees at 0.01 level; * = significant at 0.05 level.]

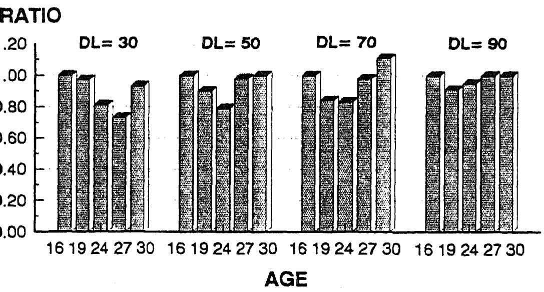
age indicate that, in both d
aged and undamaged samples, p
iodic annual increment (PAI)
inversely proportional to d
sity, and increased during
16- to 19-year period (except
30 BA where it falls slightl
PAI showed a severe decline
tween 19 and 24 years of a
which corresponds to a period
severe drought, increased s
stantially after the droug
and then remained relativ
stable during the following
years (Fig. 2). Although
initial effect of damage
diameter increment was not
severe in heavily thinned pl
(30 BA) as in other treatmen
recovery took much longer. F
lowing the storm at age 16,
PAI of damaged trees at dens
levels of 70 and 90 ft²/ac
significantly less than that
undamaged trees at both the
and 24-year measurements. The PAI of damaged trees in treatments thin
to 30 ft²/ac was not significantly different from undamaged trees un
measurements at 27 years of age.

The corrected periodic diameter increment ratio, which was adjusted
account for before-storm differences in increment between damaged and
damaged trees, indicates that the increment of damaged trees in heav
thinned plots (30 BA) was still 7 percent below that of undamaged trees
years after the storm (Fig. 3). The increment of damaged trees at all
her density levels recovered to the before-storm ratio during or before
27- to 30-age period.

The annual diameter increment of damaged trees averaged for the en
period between ages 16 and 30 was significantly less than that of undam
trees only at the lowest (30 BA) and highest (90 BA) density levels. A
though the dbh's of damaged trees at all densities were still slightly
er than those of undamaged trees at 30 years of age, they were not sign
cantly different.

<u>Height Growth</u>

An analysis of height data revealed a significant increase in the p
odic height increment of damaged trees at all density levels during th
year period following the storm (Fig. 4). In heavily thinned treatm
(30 BA), the height increment of damaged trees was more than twice tha
undamaged trees during this period. During the drought period between
19 and 24 years, the height increment of undamaged trees at all den
levels increased over that of the previous period, while that of dam
trees was greatly reduced. Height increment of damaged trees was equa
or slightly less than that of undamaged trees during the drought period



igure 3. Ratios of the periodic iameter increment of damaged to ndamaged trees during five periods f growth under four thinning re- imes. [DL = density level in t²/ac BA. Increments are corrected o adjust for any difference in amaged and undamaged samples be- ore the storm (12-16 yr).]

The corrected periodic height increment ratio indicates that the height increment of damaged trees was 5 to 21 percent less than that of undamaged trees during the drought period, depending on density (Fig. 5). During the following 3 years, the corrected height increment of damaged trees at densities greater than 30 ft² of basal area was 4 to 37 percent greater than that of undamaged trees.

The annual height increment averaged over the entire period between ages 16 and 30 was significantly greater for damaged trees at all density levels.

In all plots with density levels below 90 ft²/ac BA, taller trees were more susceptible to glaze damage. In lightly thinned

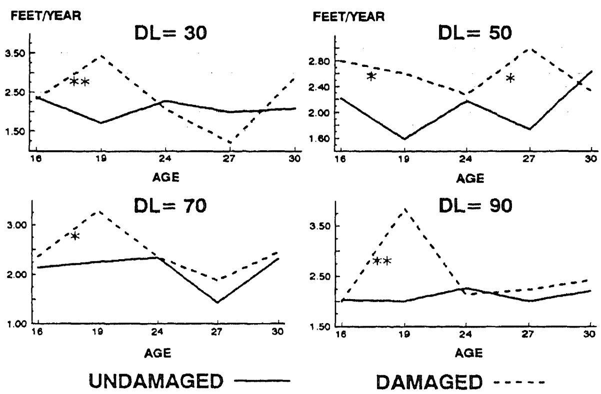


Figure 4. Effect of glaze damage on subsequent height increment of damaged trees under four thinning regimes. [DL = density level in ft²/ac BA. Mean diameters of damaged and undamaged samples at age 16 are equal. ** = significantly different from undamaged trees at 0.01 level; * = significant at 0.05 level.]

reatments (90 BA), the pre-storm height of damaged trees was slightly less han that of undamaged trees. The storm reduced total height of damaged rees by 10 to 18 percent compared with undamaged trees. The percent of eight loss increased with density. In heavily thinned plots (30 BA),

damaged trees recovered to a height equal that of undamaged trees within years. Total height recovery time increased with density. The tot height of damaged trees was significantly less than that of undamaged tre until age 19 at the lowest density (30 BA), until age 24 at 50 ft^2 /ac B until age 27 at 70 ft^2/ ac BA, and until age 30 at 90 ft^2/ac BA.

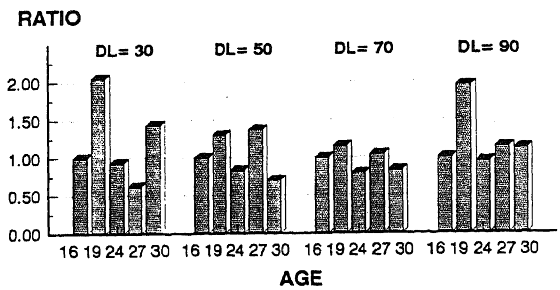


Figure 5. Ratios of the periodic height increment of damaged to undamaged trees during five periods of growth under four thinning regimes. [DL = density level in ft^2 /ac BA. Increments are corrected to adjust for any difference in damaged and undamaged samples before the storm (12-16 yr).]

Volume Growth

The immediate effects of t ice storm on stem volume (ft^3 ou side bark to a 4-inch top) we very slight since the average d ameter of the crown at breaki point was only 3 inches. Duri the first 3 years following t storm, the periodic annual volu increment was significantly low for damaged trees than for unda aged trees only at the higher de sities (70 and 90 BA) (Fig. 6).

At all densities, except t lowest (30 BA), the corrected pe iodic volume increment ratio duri the period immediately after t storm indicated that the volume i crement of damaged trees was 10 15 percent less than that of u damaged trees (Fig. 7). At t lowest density (30 BA), the volu

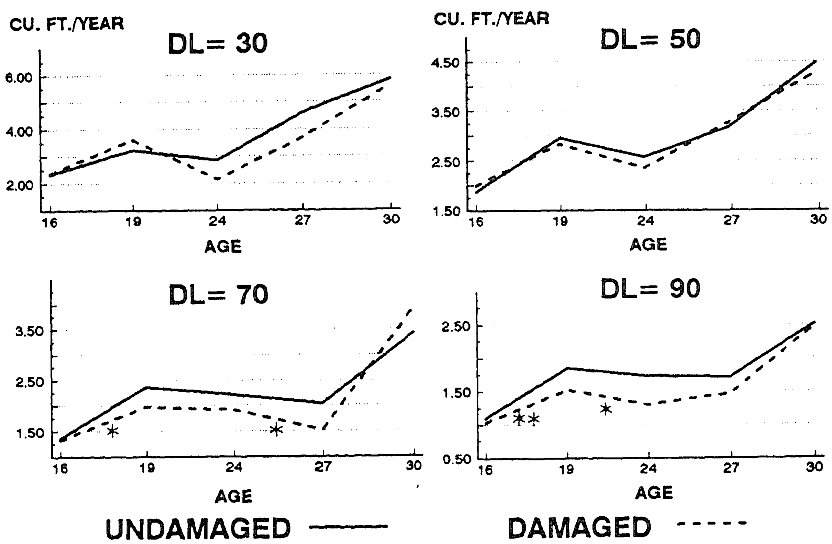


Figure 6. Effect of glaze damage on subsequent volume increment of damaged trees under four thinning regimes. [DL = density level in ft^2/ac BA. Mean diameters of damaged and undamaged samples at age 16 are equal. ** = significantly different from undamaged trees at 0.01 level; * = significant at 0.05 level.]

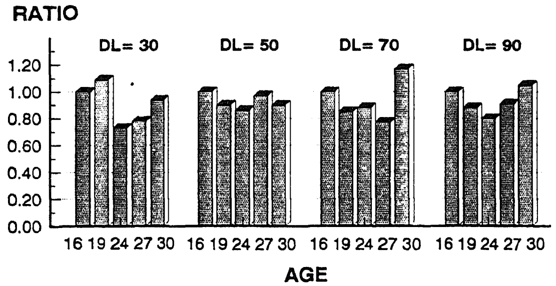


Figure 7. Ratios of the periodic volume increment of damaged to undamaged trees during five periods of growth under four thinning regimes. [DL = density level in ft^2/ac BA. Increments are corrected to adjust for any difference in damaged and undamaged samples before the storm (12-16 yr).]

increment of damaged trees was higher than that of undamaged trees; this may be due to the surge in height growth of damaged open-grown trees. At all densities (except 70 BA) the volume increment of damaged trees was more affected by the period of drought between ages 19 and 24 than was the increment of undamaged trees. By the 27- to 30-year period, the corrected volume increment of damaged trees at higher densities (70 and 90 BA) had exceeded that of undamaged trees. Volume increment was slower to recover at lower density levels. The annual volume increment of damaged trees for the 16- to 30-year period was significantly lower than that of undamaged trees only at the highest density (90 BA).

When we compare total tree volume, we see that glaze damage has a slow but significant effect on future volume, especially at higher densities. There was a reduction in the total volume of damaged trees at all densities, although it was not significant at the lower levels (30 and 50 BA). At 70 ft^2/ac BA, the total volume of damaged trees was significantly less than undamaged trees during the two periods between 19 and 27 years of age, but recovered before 30 years. At 90 ft^2/ac BA, total volume of damaged trees was significantly different from undamaged trees at the two periods between 19 and 27 years, and was still different at 30 years of age.

Conclusions

This analysis of the long-term growth data reveal that although the periodic annual diameter increment of both damaged and undamaged trees was much greater at low than at high stand densities, recovery of crown-damaged trees was slower in heavily thinned stands than in lightly thinned ones. The mean annual diameter increment of damaged trees (averaged over the 16- to 30-year period) was significantly lower than that of undamaged trees only at the highest density (90 BA). Diameters were not significantly different between damaged and undamaged samples at any thinning level during any period.

On the other hand, height recovery was retarded by density, and occurs much sooner in heavily thinned plots. During the 14 years following the glaze damage, the mean annual height increment of damaged trees was significantly higher than that of undamaged trees at all density levels. The amount of time required for recovery of damaged trees to a total height equal that of undamaged trees increased with increasing density. It occurred

at 19 years for heavily thinned plots (30 BA), at 24 years for plots thinned to 50 BA, at 27 years for plots thinned to 70 BA, and at 30 years for lightly thinned plots (90 BA).

Volume recovery was also retarded by density. As with diameter, the mean annual volume increment of damaged trees was significantly lower than that of undamaged trees only at the highest density (90 BA). There was no significant difference between damaged and undamaged trees in total volume at the lower densities. However, at 70 BA a significant difference occurred at the 19- to 24-year period, but recovery of the damaged trees took place during the 27- to 30-year period. At the highest density level (90 BA), total volume was significantly lower for damaged trees for all three periods between 19 and 30 years of age.

Loblolly pine, more than any other southern pine, is able to recover rapidly from understocking and vigorously exploits newly available space (Burton 1981). Therefore, young loblolly pine timber which has been seriously damaged by glaze can be successfully managed. Salvage of trees which have lost more than half of the crown and a thinning regime in which the "best" damaged trees are selected to remain as growing stock can result in early stand recovery. After a stand has been heavily damaged, the first impression of remaining growth potential can be misleading. Excessive salvage of trees which are capable of recouping lost volume can unnecessarily diminish future harvests. Recovery depends on density and is slower at high levels.

This preliminary analysis of growth data suggests that the dynamics of growth recovery after crown damage should be taken into consideration when forest management decisions are made. Further investigation of these data using all trees up to the thinning at 24 years (first thinning after the glaze damage) will provide larger samples and a clearer picture of the effects of crown damage on future growth.

Acknowledgments

This investigation was funded in part by the USDA Forest Service.

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FUSIFORM RUST IMPACT ON SLASH PINE UNDER DIFFERENT CULTURAL REGIMES [1]

Eugene Shoulders, James H. Scarborough, Jr., and Ray A. Arnold [2]

Abstract. The transitional probability of rust-associated tree mortality was assessed in slash pine plantations that received six cultural treatments. Results showed that tree age at infection was the most important factor affecting ability of slash pine to survive to a later age with a fusiform rust stem infection. Only 7 to 13 percent of trees infected at age 2 were alive 10½ years later whereas 30 to 50 percent of trees infected at age 3 survived for at least 10½ years. Cultural practice had little long-term impact on survival of trees infected in the second year. Control trees infected in the third year, however, survived less well than trees in the other treatments. Competition control and fertilization reduced by about 3 years the age at which an operational sanitation thinning could be made in the plantation or that the plantation could be clear cut in a commercial harvest. Probabilities for developing a stem infection before age 6 ranged from 72 percent to 93 percent. Because initial planting density was 908 trees/ac, management options for the plantation include sawtimber as the final crop with a salvage thinning whenever an operational partial cut can be made to remove diseased trees.

Introduction

Two previous papers (Nance et al., 1981, Shoulders and Nance 1987) reported the effects of fusiform rust (caused by Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme) on survival and structure of slash (Pinus elliottii Engelm. var. elliottii) and loblolly pine (P. taeda L.) plantations on ope cutover sites in Louisiana and Mi sissippi. Included in these pape were probabilities over time that tree would live or that it would d from competition or because its st had developed a fusiform rust i fection. These transitional pro abilities were based on periodic r measurements of permanent samp plots which allowed the authors specify only that a rust gall h developed or that death had occurr during the time interval between i ventories--usually 5 years.

Since these investigations we completed, additional data have be accumulated which allowed the deve opment of more precise estimates the effects of tree age at the ti rust invaded the main stem on t

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Principal Silviculturist (deceased), Computer Programmer, and Forestry Technician, Southern Forest Exp. Sta., Pineville, LA.

ability that the tree would be alive at a later date. These new data obtained from annual measurements of 1,800 trees in a study to deter- the effects of progressively more intensive cultural treatments on ival and growth of slash pine. With these new data, it was also pos- e to explore the effects, if any, of cultural treatments on transition- robabilities and to examine how disease and cultural practices have in- nced stand management options.

Materials And Methods

The study is located in central Louisiana on a site that afforded es- ally high pressure for fusiform rust infection (Burton et al., 1985). six treatments tested varied in intensity from planting on a fresh burn ompetition control (weeding) + moisture management + fertilization with ogen and phosphorus (Burton et al., 1985). Moisture management includ- oth bedding to remove excess water in winter and irrigation to elimin- summer moisture deficits. The sequence in which cultural practices added was:(1) herbaceous competition control; (2) drainage; (3) ferti- tion;(4) irrigation without fertilization; and (5) irrigation with ilization.

Treatments were replicated three times in a randomized plot design. s plots contained 18 rows of 18 trees each. Measurement plots con- ed 10 rows of 10 seedlings each and covered 0.11 ac.

Twelve-week-old container-grown seedlings were planted in late spring , after the threat of fusiform rust infection had subsided. Tree spac- was 6 ft within rows and 8 ft between rows (908 trees/ac).

Survival was inventoried annually through age 13. Total heights were ured annually through age 6 and at 7, 9, 10, and 13 years. Diameter at st height was included in inventories at 7, 9, 10, and 13 years. ng the first 5 years, fusiform rust galls from the previous growing on were recorded in March, with one exception: galls resulting from infections were recorded in March 1978. An inventory after the sixth ing season recorded height to the stem gall nearest the ground, so that ctions that were slow to develop visual symptoms could be included in l infection rates (earlier inventories inspected only the terminal th of the previous season). New infections that were identified by the edure were assumed to have occurred in the year that stem segments con- ing them were new, succulent terminal growth. The inventory at age 13 tified initial stem infections that developed after age 6 either from ct infection or from branch galls growing into the main stem.

Transitional probabilities were computed based on four mutually exclu- current conditions classes, as follows: (1) living tree free of stem s; (2) dead tree free of stem galls; (3) living tree with one or more galls; and (4) dead tree with one or more stem galls. Merchantable mes in living trees at ages 6, 9, and 13 years were computed using ey's (1985) formula for outside bark volumes of young slash pine. Data evaluated by analysis of variance using a 0.05 level of significance.

Results And Discussion

Transitional Probabilities

The effects through age 5 of cultural practices on the occurrence c stem cankers in current year growth are reported elsewhere (Burton et al. 1985). During that period, all treatments that stimulated growth increase infection rate significantly. Moreover, there were no large differences be tween growth promoting treatments (i.e., weeding and weeding plus ferti lization and/or irrigation) in the incidence of stem cankers. Transitiona probabilities through age 13 support these conclusions. Among the growt stimulating practices, probability of developing a stem canker by the ranged only from 0.89 to 0.95 (Fig. 1). Trees in the control treatmen showed a 0.79 probability of developing a stem canker by age 13.

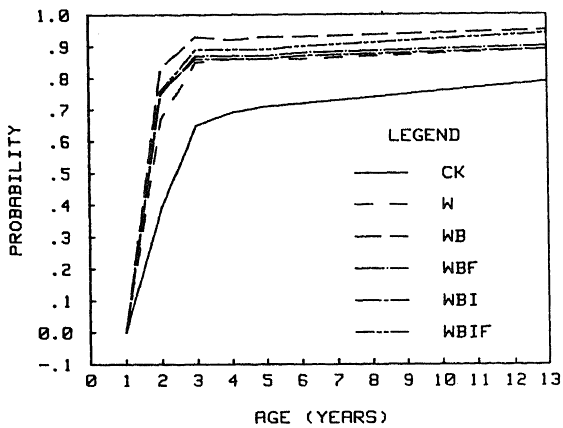


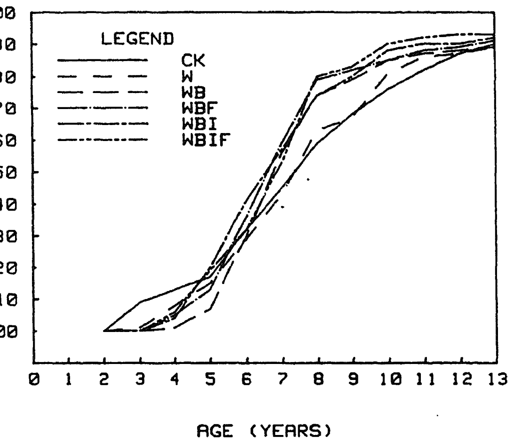
Figure 1. Transitional probabilities of developing a stem gall through age 13 by treatment (W = weeding, B = drainage, I = irrigation, and F = fertilization).

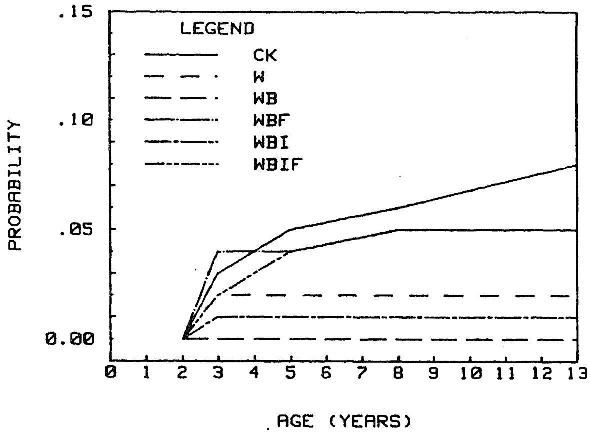
Most of the initial infection occurred during the second an third growing seasons. For tree initially infected in the secon year, the four more intensiv treatments produced similar pat terns of mortality through age 13 Probabilities of death among thes treatments ranged from 0.89 to 0.9 (Fig. 2).

Similarly, the four most inten sive treatments did not differ sig nificantly from each other in prob abilities of mortality among tree that remained free of stem canker through age 13 (Fig. 3). The mor tality that did occur in this con dition class was never greater tha one would expect from miscellaneou causes. There is no suggestion i the trends for any treatment tha significant mortality from competition had occurred. Mortality of ste galled trees had apparently provided disease-free trees with ample growin space to survive.

Trees that survive comprise the growing stock of existing stands. Fo that reason the effects of treatments and age at initial infection on th fate of stem-galled trees are reported in terms of probabilities of survi val rather than probabilities of mortality. Because no real difference developed between the more intensive treatments in transitional probabil ities of mortality and survival, only check and fertilized treatments ar included in these comparisons. Data from WBF and WBIF treatments wer pooled to derive the fertilized values.

Treatments had no long-lasting effect on survival of trees that devel oped stem galls in the second year. By age 13, probabilities for surviva of fertilized and check trees had declined to 10 and 8 percent, respective ly (Fig. 4). In the shorter term, fertilized trees were significantl





ure 2. Probabilities of death r time of trees that developed m galls in the second growing son, by treatment.

Figure 3. Probabilities of death over time of trees that remained free of stem galls through age 13, by treatment.

(W = weeding, B = drainage, I = irrigation, and F = fertilization)

s apt to survive than check trees. One factor contributing to this dif- ence was that more fertilized than check trees were broken over by an storm that occurred when trees were 7 years old.

Inidividual treatments contained too few trees that were initially in- ted in the third year for the meaningful statistical analyses to be made these data. It should be noted, however, that by age 13, probabilities survival were about 20 percentage points higher for fertilized than for ck trees in this condition class (Fig. 5).

Probabilities for survival were markedly affected by the age of the e when initial infection occured (Fig. 6). On average, there was only 11 percent probability for trees infected in the second year to survive 10½ years (i.e., to age 12). There was a 40 percent probability for es infected in the third year to survive for 10½ years (i.e., to age .

nd Dynamics And Management Options

By age 7, the fertilized treatment averaged 494 surviving trees/ac: 88 these were free of stem galls (Table 1). At age 13 there were 56 trees/ free of stem galls out of a total of 204 surviving trees. The check atment had 102 and 59 more gall-free trees and 120 and 108 more total es/ac at these ages than the fertilized treatment.

With fewer than 300 gall-free stems/ac at age 3, one might argue that h check and fertilized stands should have been destroyed and replanted h rust-resistant seedlings at that time. This is a a valid argument and that is endorsed by several authors (Belcher et al., 1977; Schmidt et , 1977; Anderson and Mistretta 1982).

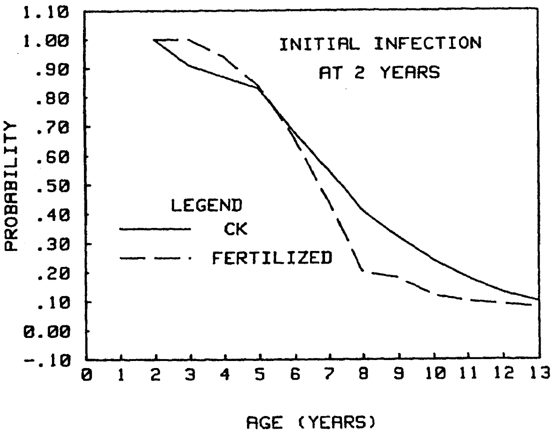


Figure 4. Probabilities of survival to a later age of trees initially infected in the second growing season.

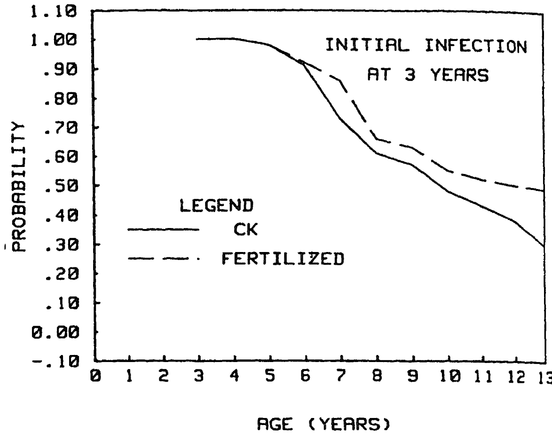


Figure 5. Probabilities of survival to a later age of trees initially infected in the third growing season.

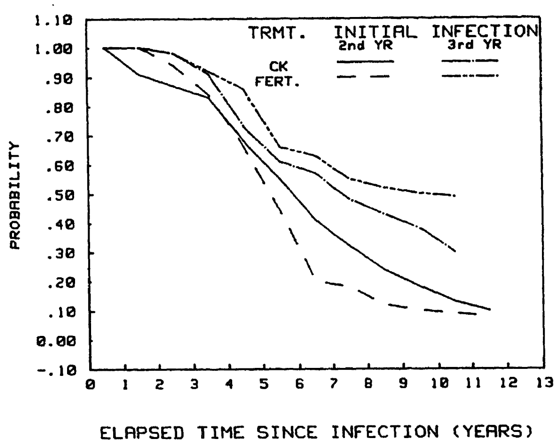


Figure 6. Effects of age at infection on probabilities of trees to survive.

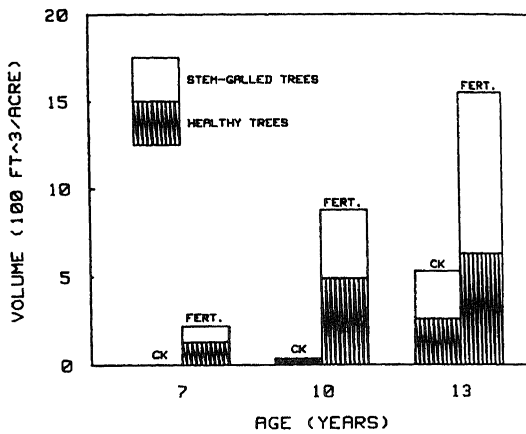


Figure 7. Merchantable volume in stem-galled and healthy trees at 7, 10, and 13 years.

A second option is to carry the stands until they contain an operable volume of merchantable wood; then to clear cut and replant with rust resistant seedlings (Anderson and Mistretta 1982). Assuming a minimum operable cut of 500 ft^3/ac, the fertilized treatment would have supported a commercial harvest by about age 9 (see Fig. 7). The check treatment would not have supported an operational clearcut until age 13.

A third option is to manage the stands primarily for sawtimber and to salvage high-risk diseased trees in sanitation thinnings when they contain sufficient volume for an operable cut (Froelich 1987). The fertilized

Table 1. Numbers of surviving trees by condition class and age.

Age	Condition Class	Treatment	
		Check	Fertilized
(yr)		(no./ac)	
7	Stem-galled	424	406
	Healthy	190	88
	Total	614	494
13	Stem-galled	197	148
	Healthy	115	56
	Total	312	204

treatment had produced sufficient volume by age 13 for this option to be applied.

The removal of all surviving stem-galled trees at this time would have produced an intermediate harvest of about 900 ft^3/ac. It would have reduced the residual stand to 56 trees/ac (Table 1). The immediate harvest of all stem-galled trees may not be necessary or even desirable under this option. Published (Nance et al. 1981) transitional probabilities for slash pine indicate that more than half of the surviving stem-galled trees should live for at least 10 years longer. Immediate harvest of about two-thirds of the volume in stem-galled trees in the stand would still produce an operable cut and would leave a residual stand of 100 trees/ac. In the "sudden sawlog" study at Crossett, Arkansas, residual stands of 48 to 63 trees/ac contained 12 to 14 thousand board feet (Int. 1/4-inch rule) of sawlogs at 30 years (Burton 1982). These stands had been thinned to 100 trees/ac by age 9 to 15 years. The present study site is at least as productive for slash pine as the "sudden sawlog" site is for loblolly pine. So this option does hold promise for the fertilized treatment.

A similar course of action might also be feasible for the check treatment if salvage thinning was delayed for another 3 to 5 years.

Conclusions

In this study, all treatments that stimulated growth increased the probability that a tree would develop a fusiform rust infection in the main stem. The growth promoting practices may have made stem-galled trees more susceptible to ice damage. Otherwise, they reduced or did not affect the probability of death by a given age.

Age at which infection occurred was the most important factor determining how long a stem-galled tree would survive. Competition control and

fertilization together reduced by about 3 years the age at which a sanitation thinning could be made in the plantation or that the plantation could be clear cut in a commercial operation. Even though rust infection is severe, sufficient gall-free and low risk trees remain for the plantation to be managed for sawtimber as the final crop with an intermediate salvage thinning to harvest diseased, poor risk trees.

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EVALUATING AND PREDICTING TREE MORTALITY ASSOCIATED WITH FUSIFORM RUST IN MERCHANTABLE SLASH AND LOBLOLLY PINE PLANTATIONS [1]

Roger P. Belanger and Stanley J. Zarnoch [2]

Abstract. Tree mortality caused by fusiform rust can limit the growth and final yield of southern pine plantations. This report quantifies and characterizes rust-associated mortality that occurred over a 7-year period in nonthinned portions of merchantable slash and loblolly pine plantations located in Alabama, Georgia, and South Carolina. Methods are presented for predicting the probability of rust-associated tree mortality in merchantable pine plantations. Results are discussed in relation to thinning and management strategies for reducing losses from fusiform rust.

Introduction

There are approximately 30 mil-on acres of slash pine (Pinus el-ottii Engelm. var elliottii) and blolly pine (Pinus taeda L.) plan-tions in the southern United ates. Many of these planted ands are infected with fusiform st, which is caused by Cronartium ercuum [(Berk.) Miyabe ex Shirai sp. fusiforme]. Fusiform rust n significantly reduce the growth, eld and product quality of south-n pines. Losses are closely re-ted to levels of infection and st-associated tree mortality (RAM) at occur throughout the life of e stand (Schmidt and Klapproth 82; Nance et al., 1983; Devine and utter 1985; Geron and Hafley 88).

Management strategies have been developed to reduce losses from fusiform rust. Choice of resistant planting material is an effective means of reducing RAM in young plantations (Schmidt et al., 1981). Selective thinning to remove trees with severe stem galls will minimize losses in older plantations (Belanger et al., 1985; Froelich 1987; Geron and Hafley 1988). The success of thinning in rust-infected stands is based on recognizing the potential for tree decline and mortality. This paper quantifies and characterizes RAM that occurred over a 7-year period in nonthinned portions of merchantable slash and loblolly pine plantations located in Alabama, Georgia, and South Carolina. Methods are presented for predicting the probability of RAM in merchantable pine plantations.

Materials And Methods

A large-scale cooperative study was established in the early 1980s to determine the biological response and economics of thinning stands with fusiform rust (Belanger et al., 1985; Miller et al., 1985).

Paper presented at Sixth Biennial uthern Silvicultural Research Con-rence, Memphis, TN, Oct. 30-Nov. 1990.

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Treatments are assessed by comparing periodic growth and total produ yield of thinned and nonthinned portions of merchantable slash and loblol pine plantations. Information about causes and rates of mortality is e sential for the evaluation of treatments and development of pest manageme guidelines. Materials and methods presented in this paper are specific the examination and evaluation of RAM in nonthinned portions of the plant tions over a 7-year study period.

Twenty plantations were selected to represent a wide range of stand a rust conditions. Ten slash pine plantations were located in the Coast Plain of Georgia and South Carolina; 10 loblolly pine plantations were l cated in the Coastal Plain of Georgia and Alabama. The areas of the pla tations ranged from 50 to 200 ac. Four ¼-ac permanent plots were esta lished in thinned and nonthinned portions of each plantation. All trees the plots were numbered to maintain their identities throughout the stud Diameter at breast height (dbh), number of stem galls, and crown class we recorded for each tree. Tree height and detailed rust characteristi (gall height and percentage of the stem circumference affected by indivi ual galls) were measured for a 20-percent subsample of the study popul tion. The stand, tree, and rust characteristics described in this pap are based on measurements of living trees taken at the time the study w initiated.

Study plots were surveyed annually for 7 years to determine cause a amount of tree mortality. RAM was defined as any dead tree with a st gall. Counts included stem-breakage if the damage occurred at a gall.

Analysis of variance was used to compare tree and rust characteristi of rust-infected dead and rust-infected living trees. Logistic regressi models were developed to predict the probability of RAM for slash and lo lolly pine. The dependent variable was

P = probability that a tree with a least one stem gall will be dead 7 years; and

the independent variables were

DBH = initial diameter breast height,
SEV = severity (percentage of stem circumference girdled by most seve gall),
GALLS = number of stem galls on a tree, and
GALLHT = mean height of stem galls on a tree.

Since observations were on an individual-tree basis, the observed d pendent variable was not a continuous probability but was a binary variab defined as one for dead trees and zero for living trees. The PROC LOGI procedure (SAS Institute Inc., 1986) with the stepwise option was used select significant variables and estimate the parameters of the logist model. The R statistic was used to measure fit of the models. This st tistic is analogous to the square root of the coefficient of multiple d termination used in the typical regression situation.

Table 1.—Stand and fusiform rust characteristics of 10 slash pine plantations used to assess rust-associated mortality.[a]

Variable	Minimum	Maximum	Mean
Stand			
Age (yr)	13	21	16
Site index (ft at 25 yr)	54	69	62
Trees (no./ac)	323	507	420
Dbh (in.)	5.2	7.3	6.2
Height (ft)	34	61	47
Rust			
Incidence (stem percent)	35	70	49
Galls/diseased tree	1.4	2.3	1.8
Stem circumference galled (percent)	57	73	62

[a] Values for stand and rust variables are from nonthinned portions of plantations at time study was initiated.

Results

tand and Fusiform Rust Characteristics

The average age of the 10 slash pine plantations was 16 years when the tudy was initiated (Table 1). Mean site index was 62 ft at base-age 25 ears. Average stocking was 420 living trees/ac, with values for in-ividual plantations ranging from 323 to 507 trees/ac. Trees were mostly ole-size, with an average dbh of 6.2 inches and an average total height of ' ft.

Both incidence and severity of rust galls were high for the slash pine antations. The average incidence of trees with stem galls was 49 per-ent, and values for individual plantations ranged from 35 to 70 percent. iseased trees had an average of 1.8 stem galls with individual galls gird-ng an average of 62 percent of the stem circumference.

Average age of the 10 loblolly pine plantations was also 16 years when e initial inventories were made (Table 2). Site index averaged 66 ft at ise-age 25 years. Stocking levels were high, averaging 480 trees/ac. ocking of individual plantations ranged from 366 to 611 trees/ac. The rerage loblolly tree was 6.7 inches in dbh and 49 ft tall. Fifty-seven ercent of loblolly trees had one or more stem galls; rust incidence of dividual plantations ranged from 49 to 73 percent. Diseased loblolly ees had an average of 2.1 stem galls with individual galls girdling 67 ercent of the stem circumference. These detailed stand, tree, and rust ta were used to characterize RAM in the study plantations.

ist-Associated Mortality

Annual mortality associated with fusiform rust over the 7-year study

Table 2. Stand and fusiform rust characteristics of 10 loblolly pine plantations used to assess rust-associated mortality.[a]

Variable	Minimum	Maximum	Mean
Stand			
Age (yr)	15	17	16
Site index (ft at 25 yr)	59	76	66
Trees (no./ac)	366	611	480
Dbh (in.)	6.2	7.1	6.7
Height (ft)	41	58	49
Rust			
Incidence (stem percent)	49	73	57
Galls/diseased tree	1.8	2.4	2.1
Stem circumference galled (percent)	57	81	67

[a] Values for stand and rust variables are from nonthinned portions of plantations at time study was initiated.

Table 3. Rust-associated mortality in merchantable slash and loblolly pine plantations.

Mortality	Slash		Loblolly	
	Trees	Volume	Trees	Volume
	no./ac	ft^3/ac	no./ac	ft^3/ac
Periodic[a]				
RAM	51.4	211.7	61.4	179.9
RAM stem breakage	7.2	46.6	1.5	9.0
Total	58.6	258.3	62.9	188.9
Annual				
Total	8.4	36.9	9.0	27.0

[a] Mortality over a 7-year study period.

period averaged 8.4 trees/ac in the slash pine plantations and 9.0 trees/ac in the loblolly plantations (Table 3). For slash pine, this tree mortality represented an average annual volume loss of 36.9 ft^3/ac. For individual plantations, annual volume losses ranged from 15-100 ft^3/ac. Stem breakage at galls accounted for 18 percent of the total volume loss in slash pine. Annual volume loss in the loblolly plantations averaged 27.0 ft^3/ac; average losses in individual plantations ranged from 13 ft^3/ac to 38 ft^3/ac.

RAM stem breakage was minimal in the loblolly plantations, representing only 5 percent of the total volume loss.

Rust-associated dead trees in the slash pine plantations had a significantly smaller dbh, had more stem galls per tree, had a larger proportion of the stem circumference galled, and the average gall was lower on the stem than for rust-associated living trees (Table 4). Seventy-two percent of RAM occurred in suppressed and intermediate trees. By comparison, only 21 percent of rust-infected living trees were in the lower crown classes. Dominant trees accounted for only 4 percent of total RAM.

Similar trends were observed in loblolly pine. RAM consisted mostly of small trees with multiple stem galls. Eighty-five percent of the trees lost were in the intermediate or suppressed crown class. Most living trees with rust were codominant and dominant trees with fewer and smaller stem galls.

Probability of Rust-Associated Tree Mortality

Logistic regression was used to model the probability of mortality of trees infected with stem galls as a function of tree characteristics and rust conditions. For slash pine, logistic regression yielded the model

$$P = 1/(1+\exp(0.39-0.044SEV+0.76DBH-0.45GALLS)).$$

The variables entered the model in the order specified in the equation and the fit statistic was $R = 0.59$. The loblolly model was

$$P = 1/(1+\exp(-6.33+1.51DBH-0.024SEV+0.12GALLHT-0.47GALLS));$$

with

$$R = 0.70.$$

Percentage of the stem circumference girdled (SEV) was the most significant rust variable in the model; DBH was the most significant tree variable. The coefficients of all parameters were biologically reasonable. Number of stem galls and severity of stem girdling can be assessed easily and quickly in the field. Four categories of potential rust mortality were defined based on the following divisions:

Number of stem galls:	1 per tree
	$\geq$ 2 per tree
Severity:	< 60 percent
	$\geq$ 60 percent.

The influence of these rust characteristics on actual tree mortality in nonthinned slash pine plantations is shown in Table 5. Mortality was less than 10 percent for trees with < 60 percent stem girdling regardless of the number of stem galls present. Risk of mortality will likely remain low for these trees. Number of stem galls did, however, influence the amount of RAM for trees with $\geq$ 60 percent of the stem girdled by rust. Mortality for trees with severe stem girdling and only one stem gall was 31 percent. Risk of mortality was defined as moderate for these trees. High-risk trees have two or more stem galls, at least one of which girdles 60 percent or more of the stem circumference. Mortality for high-risk slash pine trees was 48 percent.

Table 4. Characteristics of rust-associated dead and rust-associated livi[ng] slash and loblolly pine trees.

Variable	Pine			
	Slash		Loblolly	
	Rust-associated			
	Dead	Living	Dead	Living
Tree				
Dbh (in.)	5.5a[1]	6.9b	5.1a	7.1b
Height (ft)	45.1a	50.1b	43.3a	50.3b
Volume (ft^3)	4.4a	6.9b	3.0a	6.6b
Rust				
Galls/diseased tree	2.1a	1.6b	2.1a	1.7b
Stem cir. galled (percent)	77.3a	54.9b	66.6a	48.1b
Gall ht (ft)	9.6a	12.7b	6.9a	9.9b
Crown class (percent)				
Dominant	4	29	1	20
Codominant	24	50	14	64
Intermediate	52	20	57	15
Suppressed	20	1	28	1

[1] For a given species, univariate means not followed by the same letter are statistically different (Tukey's test: P = 0.05).

Table 5. Number and severity of stem galls influence the observed percentage of rust-associated mortality for individual slash pine trees.

Severity[b]	Percentage of rust-associated mortality [a]	
	Number of stem galls	
	1	$\geq$ 2
< 60	7/90 = 0.08	0/42 = 0.00
$\geq$ 60	38/122 = 0.31	88/184 = 0.48

[a] Values based on mortality in merchantable nonthinned slash pine plantations over a 7-year study period.

[b] Severity = Percentage of stem circumference girdled by most severe gall.

The influence of rust severity and number of galls on tree mortality in blolly pine plantations is shown in Table 6. RAM for low-risk loblolly ne trees was 10 percent, increased to 30 percent for moderate-risk trees, d culminated at 41 percent for high-risk trees. Comparison of data for ash pine and loblolly pine indicates that rust characteristics influence dividual tree mortality for the two species in much the same way.

ble 6. Number and severity of stem galls influence the observed percent- e of rust-associated mortality for individual loblolly pine trees.

verity[b]	Percentage of rust-assoicated mortality [a] — Number of stem galls: 1	≥ 2
< 60	7/169 = 0.10	9/89 = 0.10
≥ 60	34/115 = 0.30	86/209 = 0.41

Values based on mortality in merchantable nonthinned loblolly pine plantations over a 7-year study period.

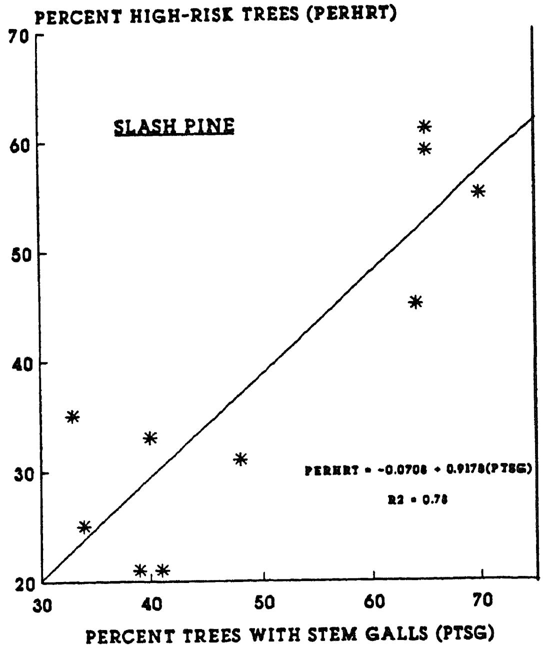
Severity = Percentage of stem circumference girdled by most severe gall.

The probabilities of RAM for all trees were predicted from the logistic dels and compared to the actual risk classification values presented in bles 5 and 6. In all instances, the mean predicted probabilities for the sk categories were similar (+ 0.08) to the observed values.

The potential for mortality and volume loss is greatest in stands with high proportion of high-risk trees. Since stand inventories often con- in the percentage of trees with stem galls, simple linear regressions re developed to predict percentage of high-risk trees on the basis of st incidence. For slash pines there was a close relationship ($R^2 = 0.78$) tween the percentage of high-risk trees and the percentage of rust (Fig. . This relationship weakened ($R^2 = 0.45$) for loblolly pine (Fig. 2). her tree or stand variables did not have a significant effect on percent- e of high-risk trees.

Discussion

Fusiform rust is a detrimental component of many merchantable slash and blolly pine plantations. It is important that the potential for rust-



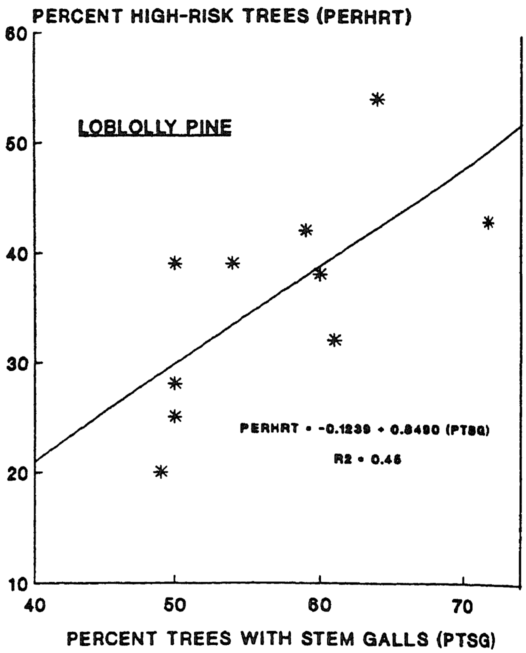


Figure 1. Relationship between percentage of high-risk trees and percentage of trees with stem galls for slash pine.

Figure 2. Relationship between percentage of high-risk trees and percentage of trees with stem galls for loblolly pine.

associated losses be recognized in the planning and practice of plantation management. Incidence of rust can vary considerably depending on environmental, biological, and cultural conditions specific to sites. Losses from rust-associated mortality, reduced growth, and product degrade obviously increase as rust incidence increases. This study shows that there is a strong relationship between rust incidence and levels of probable tree mortality. For slash and loblolly pine, as the proportion of trees that have stem galls increases, the proportion of these trees that are high-risk and likely to die also increases.

Thinning is a silvicultural means of salvaging potential RAM. Number of trees removed will depend on required residual spacing, selected stocking level, and specific management objectives. Risk associated with severity of rust infections should determine what trees to remove. Trees with severe stem girdling and multiple galls should be selected first. The risk of RAM is highest for these trees. Moderate-risk trees--stem with one severe gall--should have second priority in thinning. Low-risk trees can be removed as needed. The removal of trees with severe or multiple stem infections is particularly important when the management objective is to grow an optimum yield of quality sawtimber.

The results and recommendations presented in this paper are based on 7 ars of detailed measurements and annual surveys of RAM. Although prob-ility values will increase with time, it is unlikely that trends in RAM ll be significantly altered over the course of normal 25- to 30-year ro-tions. Tree mortality and volume loss associated with high-and moder-e-risk trees will continue to be a problem unless corrective measures are ken. Selective thinning of diseased trees will salvage potential mor-lity caused by fusiform rust, improve stand quality, and amend forest alth.

Acknowledgments

Research reported in this paper was supported in part by the Integrated rest Pest Management Cooperative centered in Gainesville, FL.

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OAK DECLINE IN THE LOWER MISSISSIPPI RIVER VALLEY [1]

rancis I. McCracken, Vernon Ammon, James D. Solomon, and T. Evan Nebeker [2]

Abstract. Oaks in some areas of the South have been seriously affected by decline and mortality. Losses are apparently caused by a variable complex of biotic and abiotic factors. This study was undertaken to characterize decline and to develop a hazard rating system. Discriminant analysis identified 10 functions that explain 82 percent of the variation between decline and control plots. Canonical function analysis indicated that decline plots tend to have less growth, fewer dominant trees, poorer crown condition, and higher soil pH. Stress periods associated with droughts and storms were identified in growth ring analysis. Mean annual basal area increment (BAI) differentiated control from decline plots for several decades before decline symptoms appeared. Recent decreases in BAI at some locations appear related to reduced summer rainfall.

Introduction

Oaks and associated hardwoods e among the most valuable timber sources in the south central Unid States, providing about oneird of the national sawtimber vole, unique habitat for many other ants and animals in both wetland d upland forests, and recreational portunities for many people.

Decline in vigor and death is an derly natural process in hardwood rests as with other life systems. However, when decline and death proceed faster than expected for a given site and species combination, private and public user groups become concerned. Research can provide information on the nature of decline and associated conditions that will help reduce losses to more satisfactory levels. However, results to date have not identified the causes of oak decline, nor have they provided enough information to deal with oak decline. A knowledge of the complex interaction of host, stand, site, climate, pests, and other factors involved in decline is needed.

More than 26 decline events affecting nearly all oak species in eight eastern states have been reported over the last 130 years. Fourteen factors have been cited as primary or secondary agents contributing to decline and death, including late freeze (Beal 1926), drought (Balch 1927, McIntyre and Schnur 1936, True and Tryon 1956, Staley 1965, Lewis 1981, Tainter and Bensen

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Paper presented at Sixth Biennial uthern Silvicultural Research Conrence, Memphis, TN, Oct. 30-Nov. 1990.

Principal Research Pathologist, uthern Forest Exp. Sta., Stonelle, MS; Associate Professor, Misssippi State Univ., MS; Principal search Entomologist, Southern Fort Exp. Sta., Stoneville; and Prossor, Mississippi State Univ., MS.

1983), two-lined chestnut borer (Chapman 1915, Staley 1965, Dunbar and Stephens 1975), gypsy moth (Baker 1941, Skelly 1974), armillaria root rot (Long 1914, Baker 1941, Fergus and Ibberson 1956), hypoxylon canker (Thomas and Boza 1983), Ganoderma root rot (Lewis 1981), aspect (Gillespie 1956, Kegg 1973), slope (Gillespie 1956, Tryon and True 1958), poor soils (Hursch and Haasis 1931, Staley 1965), encroachment of civilization (Knull 1932), and changing climate (Hepting 1963).

Numerous biotic and abiotic agents apparently act together in a poorly understood complex to cause oak decline. Current challenges to research include identifying the factors that cause decline, pinpointing where and how these factors contribute to decline, and evaluating their individual or collective impact. Our objectives were to collect biological and edaphic data to gain insight into the causes of decline and to develop a predictive model of oak decline in the mid-South. The model will help to identify stands that require silvicultural treatments to prevent or lessen the effects of decline and will prioritize among stands needing treatment.

Materials And Methods

Hardwood forests within the Mississippi River drainage basin were observed. Plots were located on the Mark Twain National Forest, MO; Trigg County, KY; Tipton County, TN; Black River Wildlife Management Area, Arkansas; Hurricane Lake Wildlife Management Area, AR; White River National Wildlife Refuge, AR; Delta Experimental Forest, MS; Delta National Forest, MS; Bluff Experimental Forest, MS; and the Tensas River National Wildlife Refuge, LA. Variable-radius plots containing declining trees were established using a 10-basal-area factor angle gauge. Plots containing trees free of decline symptoms were established as controls. Tree and stand data recorded for each plot included species, diameter, basal area, form, logs, sticks, crown class, crown condition, last year's growth, growth last 5 years, and growth last 10 years (Table 1). The growth increment of three trees in each plot was metered to the nearest 0.01 mm (both metric and English measuresment units have been used; hence, inconsistencies may occur) with a Henson computer-compatible incremental measuring instrument. Sample trees were cross-dated and annual radial growth increments were converted to mean basal area increment (BAI). Climatic data from the nearest recording station were matched and compared with the growth data at several locations. Site data recorded were slope, aspect, topographic position, site index, percentage of organic matter, pH, cation exchange capacity, and mineral analysis (N, P, K, Ca, Mg, Zn) (Table 2).

Discriminate analysis and canonical analysis (Klecka 1980) were used to distinguish between control and decline plots in the model development phase of analysis. Visual interpretation of graphs helped to identify trends.

Results

Data were collected from more than 3,000 trees in 151 field plots at 10 locations in 6 states in the Mississippi River drainage basin. One hundred five field plots contained trees in various stages of decline, and 46 contained trees with no evidence of decline.

Table 1. Tree variables measured on decline and control plots in the Mississippi River drainage basin.

Tree variable	Recorded
Species	Species
Diameter	Inches at dbh
Basal area	Square feet (ft^2)
Form	1 = Straight bole, no major branching 2 = Some stem curvature and/or major branching in first log 3 = Crooked or hollow bole
Logs	Number of 16-ft logs for trees over 10 inches dbh
Sticks	Number of sticks (5-ft cylinder of wood at least 4 inch diameter) for trees under 10 inches dbh.
Crown class	1 = Dominant 2 = Codominant 3 = Intermediate 4 = Suppressed
Crown condition	1 = Healthy tree 2 = < 1/3 of crown affected 3 = 1/3 to 2/3 of crown affected 4 = >2/3 of crown affected 5 = Dead tree
Growth (radial)	Millimeters (in last year, 5 years, and 10 years)

ree and Stand Variables

Red oak (*Quercus falcata* spp.) species predominated in both decline and ontrol plots, averaging 60 and 55 percent, respectively, with white oak Q. *alba* spp.) species accounting for 12 percent of the trees in decline lots and 11 percent in the control plots. Nineteen other hardwood species omprised the balance of 20 to 30 percent (Fig. 1A). Typical decline and ontrol plots contained from 11 to 12 trees averaging 18.8 inches in dimeter and 1.6 logs (Fig. 1B). Approximately 63 percent of the trees growng in control plots exhibited straight boles without major branching, 15 ercent had some curvature and/or major branching in the first log, and 16 ercent were crooked or hollow. Percentage distribution of trees in decline plots within form classes 1, 2, and 3 was 61, 13, and 16 percent, espectively (Fig. 1C). Distribution of crown classes of trees in decline nd control plots was similar (Fig. 2A). Sixty-seven percent of the trees n both control and decline plots were dominant or codominant.

Table 2. Site variables measured in decline and control plots in t
Mississippi River drainage basin.

Site variable	Recorded			
Slope	Percent			
Aspect	0 = N	1 = NE	2 = E	3 = SE
	4 = S	5 = SW	6 = W	7 = NW
Topographic position	1 = Upland ridge		2 = Side slope	
	3 = Upland bench		4 = Upland bottom	
	5 = Bottomland slough		6 = Bottomland flat	
	7 = Bottomland ridge		8 = Bottomland terrace	
Site index	Height and age of three dominant/codominant red oaks			
Soil components	pH, percent organic matter, cation exchange capacity mineral analysis (N, P, K, Ca, Mg, S, Zn)			

In decline plots, 11 percent of the trees were dead and 51 percent w expressing foliar, twig, and branch decline symptoms in one-third of th crowns. Another 9 percent of the plot trees exhibited decline in one-th to two-thirds of the crown (Fig. 2B). Mean radial growth for trees in cline plots for the previous year was only 1.5 mm, compared with 2.5 mm trees in control plots. Mean 5- and 10-year growth increments of trees decline plots were 8.1 mm and 16.5 mm, respectively, whereas those in c trol plots grew markedly better, averaging 12.8 and 26.5 mm during the s periods (Fig. 2C).

Site Variables

Most of the plots were on sites with less than 5 percent slope (F 3A) and north aspect (Fig. 3B). The topographic positions of 76 percent the control plots and 69 percent of the decline plots were classified either bottomland ridges or bottomland flats. (Fig. 3C). Basal area/ac site index for decline plots averaged 125 and 90, respectively, and control plots, 115 and 98. Recorded soil characteristics varied by lo tion; however, soil pH was consistently higher in decline plots than control plots.

Weather Factors

Direct comparisons of mean annual radial growth and annual rainfall Stoneville, MS, showed a distinct relationship. Major periods of low ra fall, such as the drought periods during the mid-1920s, 1940s, 1950s, 1960s corresponded with reduced growth. Tree crown damage from accumu tion of glaze ice in the early 1970s apparently slowed growth despite a quate rainfall (Fig. 4). Similar results were obtained at locations Missouri and Mississippi where weather records were available. The m BAI of decline and control plots at Stoneville, MS, distinguishes two d tinct populations since 1940 (Fig. 5). Comparable results were obtained

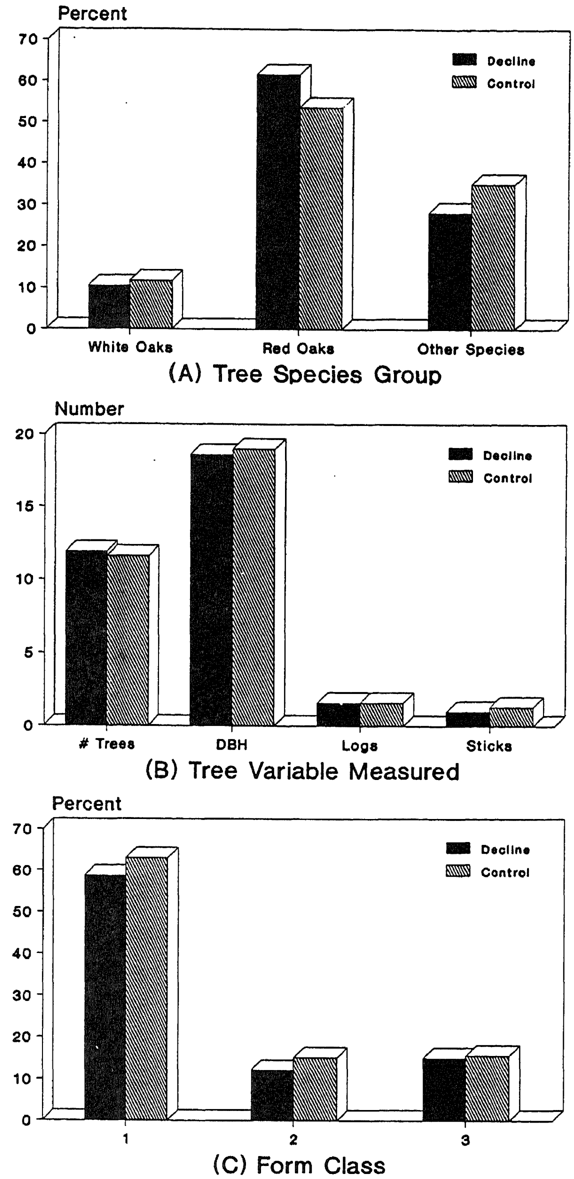

Figure 1. Tree and stand variable means on decline and control plots. (A) Percentage of tree species by groups; (B) number of trees per plot, dbh, logs, and sticks; (C) percentage of trees in form classes 1-3 (see Table 1).

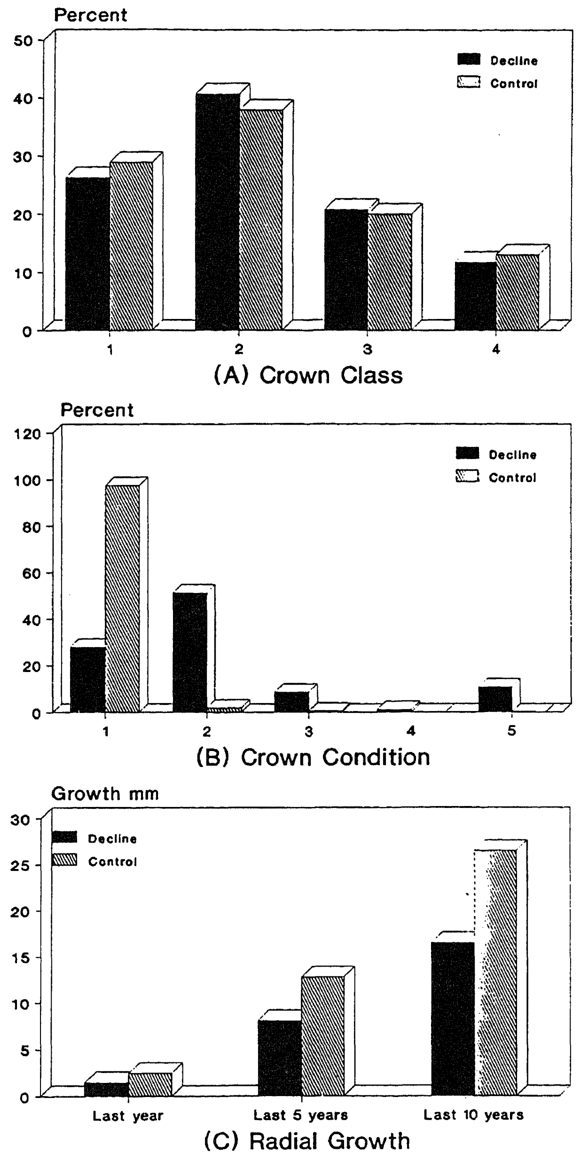

Figure 2. Tree and stand variable means on decline and control plots. (A) Distribution percentage by crown class; (B) percentage of crown conditions 1-5 (see Table 1); (C) radial growth in last year, last 5 years, and last 10 years.

all other locations except those near Vicksburg, MS, and Covington, TN. However, separation of decline from control populations varied by several years.

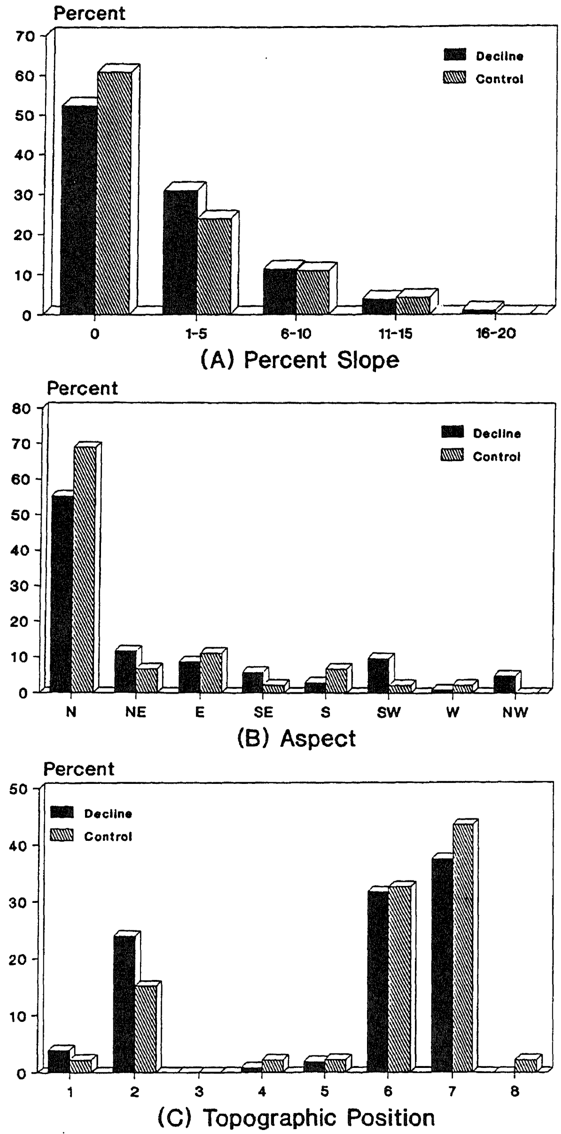

Figure 3.—Mean percentage site variables of decline and control plots. (A) Slope; (B) aspect; (C) topographic positions (see Table 2).

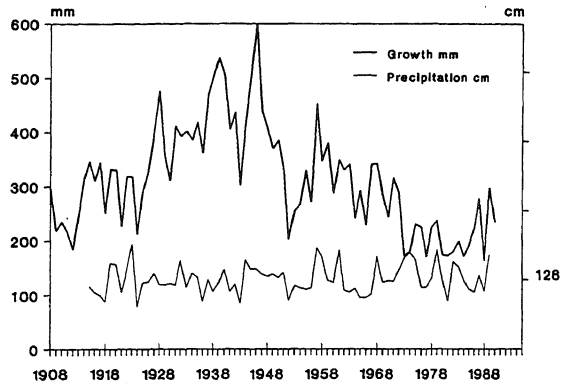

Figure 4. Mean annual radial growth (mm) and precipitation (cm) of oaks on the Delta Experimental Forest, Stoneville, MS.

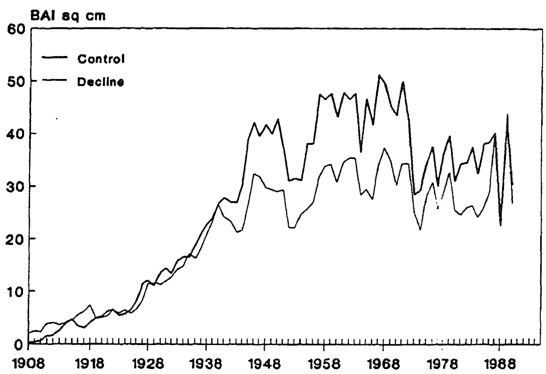

Figure 5. Mean basal area increment (cm^2) in decline and control plots on the Delta Experimental Forest, Stoneville, MS.

Conclusions

Preliminary analysis of data collected from plots in the Mississippi River drainage basin identified 10 discriminant functions that explain 82 percent of the variation between decline and control plots. Subsequent canonical function analysis indicated the following tendencies for selected

variables in decline plots: soil pH is higher, growth is less, there are fewer dominant trees, and percent crown conditions 2 (< 1/3 of crown affected) and 4 (> 2/3 of crown affected) are higher. Previous stress periods associated with droughts and winter storms were evident in growth ring analysis. The mean annual basal area increment (BAI) differentiated control from decline plots for several decades. However, separation of decline from control plots by BAI varied by location, indicating that site and stand factors are involved rather than specific timed events. These data indicate that long-term climatic trends accompanied by short-term environmental and biological stress factors are involved in hardwood decline and mortality. Continuing analysis and research will attempt to identify additional, more specific, nonvisual indicators of standard sites subject to decline.

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EXPLORING VARIATION IN THE CONSTITUTIVE DEFENSIVE SYSTEM OF WOODS RUN AND FULL-SIB FAMILIES OF LOBLOLLY PINE IN RELATION TO BARK BEETLE ATTACK [1]

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Abstract. The constitutive defensive system of southern yellow pines has been the subject of considerable research efforts over the past few years in relation to bark beetle attack. During 1988, 1989, and 1990 trees of unknown parentage (woods run) were wounded at different times during the day and total resin flow measured hourly for 24 hours. Rate of flow was calculated. Significant differences in flow were found at the beginning of the 24-hour period for all years. The year 1988 was the only period that these differences continued for the entire 24 hours. Patterns of flow were similar for all years with 70 to 87 percent of flow occurring within the first 8 hours after wounding. Total flow over a 4-hour period, rate of flow, and relative viscosity were measured on 14 full-sib families in 1987. Significant differences between families were detected for all parameters measured. These parameters have been suggested as being useful in predicting relative host susceptibility to bark beetle attack. Certain families are suggested to be potentially more resistant to bark beetle attack than other families based on these parameters of interest. Findings presented here, although preliminary, are encouraging in that it may be possible to incorporate potential bark beetle resistance information into tree improvement programs.

Introduction

Forest pests, principally in-ects, cause millions of dollars in oss to the economy annually. Much esearch effort has been expended on hese pests, but most of the re-earch has been fragmented. It has ealt with only one aspect of the roblem, such as insect biology, ampling, population dynamics, stand hazard rating, or direct control measures. These research efforts have added immensely to our understanding of the pests and the hosts, but in no case have we progressed to the point where we have really effective means for controlling or keeping the pest in check. The major reason why we have not been more successful is that for most pests, and especially the insects, we still do not understand the very basic interactions which take place between the pest and the host tree. For example, with the southern pine beetle (SPB) (Dendroctonus frontalis Zimm.) we have been unable to explain how the beetle and its associated fungi overcome the natural resistance of the tree, colonize, reproduce, and ultimately kill the tree. Such basic information is essential for effective pest management.

Paper presented at Sixth Biennial outhern Silvicultural Research Con-erence, Memphis, TN, Oct. 30-Nov. , 1990.

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The work presented here is a continuation of a previous study (Nebeker et al. 1988). The specific objectives of that study were to determine the variability and extent to which specific traits of the constitutive defensive system of loblolly pine (Pinus taeda L.) are controlled by environmental versus inherited characteristics, and to relate trait variability to known population processes of the SPB. In the previous study, Nebeker et al. (1988): (1) reviewed known factors associated with SPB infestations; (2) suggested that information concerning the oleoresin secretory system be utilized in tree improvement programs to increase the potential resistance to bark beetle attack; (3) described the methodology that was developed to address questions concerning the following components of the constitutive defensive system (specifically total resin flow, relative viscosity, rate of initial flow, and resin duct densities); and (4) compared these components with respect to specific half-sib families at different locations. The traits which they investigated included physical and morphological characteristics of the oleoresin secretory system. Here we will address only the physical characteristics of the oleoresin secretory system. The objectives of this study were to: (1) determine if differences occurred in total resin flow and rate of resin flow in relation to time of wounding; and (2) determine if there were differences in total resin flow, rate of resin flow, and relative viscosity between 13 full-sib families of loblolly pine.

Methods And Procedures

Time of Wounding

Total and rate of resin flow were determined on loblolly pine trees that originated from a local, unselected natural seed source. The trees were located in a plantation on the John W. Starr Memorial Forest in Mississippi. Trees were 31 years of age in 1988. They were sampled during 1988, 1989, and 1990. Oleoresin flow was determined by wounding the tree with a 2.54-cm diameter arch punch. Care was taken to prevent scoring of the xylem. The goal was to cut through the corky bark and phloem to the cambium. After the wounding, a triangular-shaped piece of aluminum, with edges folded upward (P. L. Lorio, Jr., personal communication 1987), was placed under the wound in a groove cut into the bark to direct the flow of resin into a section of disposable pipette for collection and measurement. The pipette was attached to the tree using a fencing staple or a rubber stopper and nail. Four wounding times, 8:00 a. m., 12:00 p.m., 3:00 p.m., and 7:00 p.m., were used in 1988 and 1989. During 1990 wounding times were 7:00 a.m., 11:00 a.m., 3:00 p.m., and 7:00 p.m. Resin flow was recorded hourly for each start time for 24 hours. The first wound was made on the north aspect followed by the west, south, and concluded on the eastern aspect for the four wounding times. This was done to simplify recording of the data; there is no relationship between position of wound and resin flow (Nebeker, unpublished data). Twenty trees were used in 1988 and 1990, while 24 trees were used in 1989.

Full-Sib Families

The data for 13 full-sib families were collected from a 21-year-old loblolly pine plantation located near New Burn, North Carolina, during

987. Each family consisted of a minimum of three replicates. Rate of low was measured by first drilling a hole (0.95 cm diameter x 2 cm deep) hrough the bark and into the outer layers of xylem (at breast height) and riving a glass tubing (10-cm long, 9 mm outside diameter, and 2.9 mm in-ide diameter) into the hole leaving a gap to provide a reservoir for the esin to collect. Rate of flow was then determined by timing the resin eadflow over a certain distance through the flow tube. Total flow was etermined by attaching a pipette to the end of the tube and allowing it to low for 4 hours.

Relative viscosity was determined by dropping a BB (34.5 g) into the esin that had accumulated in the pipettes. The time it took the BB to ravel 20.5 mm, the distance between 1-ml markings on the pipettes, or).25 mm, the distance between 0.5-ml markings, was recorded. Measurements ere made as soon as 1.5 ml of resin had accumulated, or at the end of the -hour period if at least 0.9 ml of resin was available. Pipettes removed efore the end of the 4 hours were replaced with new pipettes. If it ap-eared the BB was being hampered due to crystallization of the resin, the ample was discarded.

Data were analyzed using analysis of variance (ANOVA) with alpha equal o 0.05 for all analyses. If results of ANOVA indicated significant dif-erences, then the Least Significant Difference procedure (LSD) was used to etermine where those differences occurred. The analyses were accomplished sing SPSS V.40 computer program ONE-WAY (SPSS Inc. 1990). Appropriate ransformations were performed to meet assumptions of homogeneity of var-ance where necessary.

Results

ime of Wounding

1988. Trees wounded at 7 p.m. had significantly greater flow than rees wounded at 8 a.m. and 12 p.m. for the first hour and for hours 10 hrough 24 (Fig. 1). From hours 2 through 9, trees wounded at 7 p.m. had ignificantly greater flow than trees wounded at 8 a.m. There were no sig-ificant differences between trees wounded at 3 p.m. and other wounding imes. The rate of flow was greatest for all groups during the first 2 ours except for the trees wounded at 7 p.m., which decreased between the irst and second hour (Fig. 2). After the second hour the rate of flow de-reased rapidly for all groups until the eighth hour after wounding. After his time all flow rates leveled off at very low values. Between 70 and 76 ercent of the total flow occurred within the first 8 hours after wounding.

1989. Trees wounded at 12 p.m., 3 p.m., and 7 p.m. had significantly reater flow than trees wounded at 8 a.m. for the first hour. For the sec-nd and third hours after wounding, the total flow for trees wounded at 12 .m. and 3 p.m. was greater than the flow for trees wounded at 8 a.m.. The low for the trees wounded at 7 p.m. was not significantly different from ny other groups during this time. For the remainder of the 24-hour period here were no significant differences in total flow between any of the

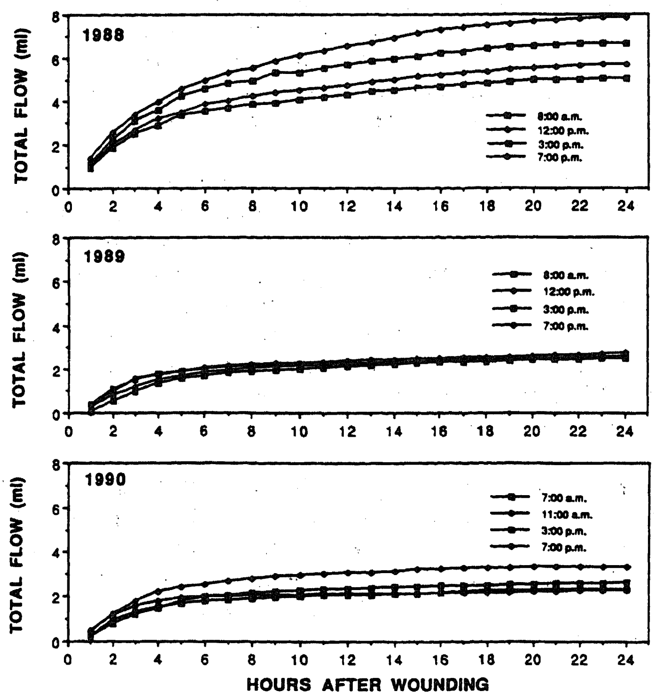

Figure 1. Total resin flow for trees of unknown genetic history on the John W. Starr Memorial Forest, Mississippi, beginning 1 hour after wounding for 24 hours.

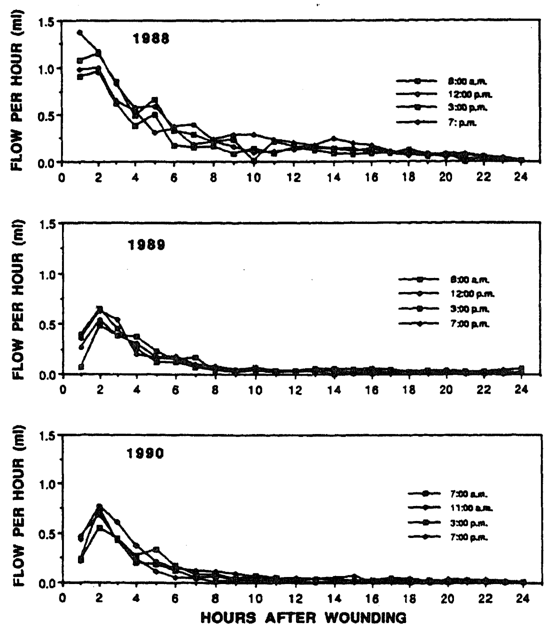

Figure 2. Resin flow per hour for trees of unknown genetic history on the John W. Starr Memorial Forest, Mississippi, beginning 1 hour after wounding for 24 hours.

roups. Rate of flow was similar for all groups. There was an increase in ate of flow between the first and second hour, after which there was a apid decrease until the eighth hour after wounding. After this time all low rates were approaching zero. Between 70 and 86 percent of the total low occurred within the first 8 hours after wounding.

1990. Trees wounded at 11 a.m. had significantly greater flow than rees wounded at 8 a.m. for the first hour. For the remainder of the 24-our period there were no significant differences in total flow between any f the groups. The results for flow-per-hour were similar to those obtaind in 1989. There was an increase in rate of flow between the first and econd hour, after which there was a rapid decrease until the eighth hour fter wounding. After this time, all flow rates leveled off at very low alues. Between 82 and 87 percent of the total flow occurred within the irst 8 hours after wounding.

The results obtained in 1988, 1989, and 1990 were similar in patterns f resin flow to those obtained in 1987 (Nebeker et al. 1988). No significant differences in resin flow were found at any time in 1987, however here were no 3:00 p.m. or 7:00 p.m. wounding times. In the 3 years folowing the initial study all significant differences involved the 3:00 p.m. r 7:00 p.m. wounding times.

ull-sib Families

Total flow. There were significant differences among the full-sib famlies for total resin flow ($F = 5.5934$; $df = 12, 42$; $P<0.0001$) (Fig. 3). amilies 1, 2, 3, 5, and 6 have a parent in common and had the highest toal flow. Families 11 and 13 had the lowest total flow and had a parent in ommon. This finding suggests that the constitutive defensive system is nder genetic control.

Rate of flow. There were significant differences among the full-sib amilies for rate of flow ($F = 4.7019$; $df = 11, 34$; $P = 0.0002$) (Fig. 4). ate of flow for Family 10 was omitted due to a limited sample size of one. he greatest rate of flow occurred in Family 13 while the least rate of low occurred for Family 9.

Viscosity. Through the analysis of variance it was also determined hat there were significant differences among the full-sib families for elative viscosity ($F = 8.370$; $df = 12, 132$; $P < 0.0001$) (Fig. 5). The reatest relative viscosity occurred in Family 13 and the least in Family .

Discussion

The constitutive defensive system of loblolly pine is important in the tudy of tree resistance to bark beetle attack. Mason (1971) made a simiar statement when attempting to explore the factors that influence oleoesin flow. Lorio and Hodges (1977) demonstrated that reduced oleoresin xudation flow is associated with successful attacks by the SPB. Their daa showed a flow of 8.4 and 5.6 ml for unsuccessful attacks, and 1.6 ml for

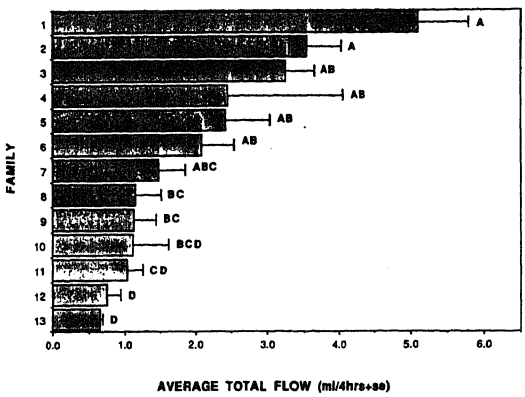

Figure 3. Total resin flow for 14 full-sib families near New Burn, North Carolina.

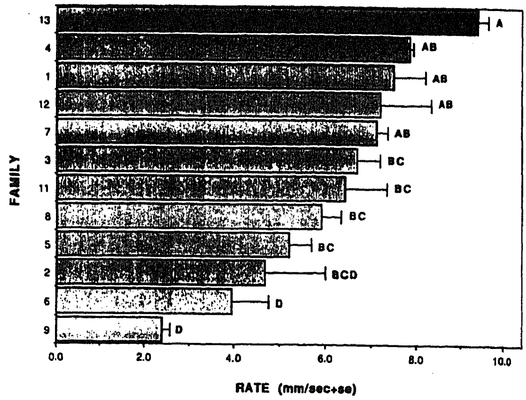

Figure 4. Rate of resin flow for 14 full-sib families near New Burn, North Carolina.

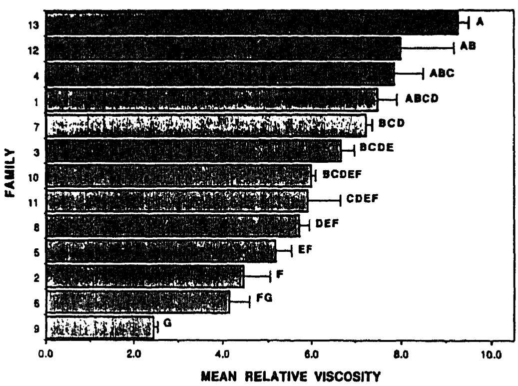

Figure 5. Mean relative viscosity for 14 full-sib families near New Burn, North Carolina.

successful initial attack. It is interesting that our total flows were similar, but our wound size was much smaller. We would suggest that a possible reason for the differences are in association with the environmental conditions during the observation periods. During 1988, we observed nearly four times as much total flow than in 1989 and over twice the total flow as in 1990.

Resin viscosity is another variable used in distinguishing SPB-resistant and susceptible loblolly pines (Hodges et al. 1977, 1979). Viscosity is also believed to be genetically controlled (McReynolds 1971). The resistance mechanism can be viewed as a persistent barrier to colonization, acting by slowing down the beetle, and hence increasing the probability of mortality. Theoretically, viscosity is governed primarily by the chemical composition of the resin, especially the level of monoterpenes, since these compounds act as solvents for the resin acids. The greater the concentration of resin acids, which are the most toxic components of oleoresin, the greater the viscosity.

Nebeker, et al. (1988) suggested that tree improvement programs in general have not been aimed at improving resistance to bark beetles. Numerous other criteria have been utilized in selecting material for propagation.

/e suggest that now, with our increased understanding of the constitutive ınd induced defensive systems within pine, we can begin to look to the sel- ection of material that would be less susceptible or suitable to bark ɔeetle attack and colonization. There is still a tremendous lack of know- ledge as to the impact these systems have on the dynamics of the bark be- etle and associated populations. However, with our increased knowledge of these systems we can select trees for controlled experiments to determine he impact on the dynamics of these economically important pest species.

Acknowledgments

We are grateful to Weyerhaeuser Company for providing the study sites ınd appropriate documentation associated with these sites. Funds for this study were provided in part through the Mississippi Agricultural and Fores- ry Experiment Station, Contribution Number PS-7625 and the USDA Office of Grants and Program Systems Competitive Research Grants Program, Insect Pest Science-Bark Beetles No. 86-CRCR-1-2114.

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THE APPLICABILITY OF STEM ELECTRICAL RESISTANCE IN RATING LOBLOLLY PINE TREE VIGOR [1]

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Abstract. This investigation was conducted to determine the applicability of stem electrical resistance (SER) as a means for assessing loblolly pine (Pinus taeda L.) tree vigor. The investigation consisted of: (1) measuring SER of dominant, intermediate, and overtopped trees growing in 28 stands with different site indices; (2) monthly measurements of SER of dominant trees from six plots with varying site indices; and (3) relating SER with tree and site variables from stands representing bottomland and upland sites. SER was found independent of site index and was effective in differentiating the three crown classes of loblolly pine trees. Monthly measurements of SER revealed a definite seasonal pattern with the period of most active growth coinciding with the period of lowest SER values. SER was inversely related to all the tree and site variables except soil moisture which was positively correlated for bottomland site and negatively correlated for upland site. Monthly air temperature was the most highly correlated variable with SER, thus partially explaining the high degree of seasonality in SER.

Introduction

There is a close association between tree vigor and southern pine beetle (Dendroctonus frontalis Zim.) (SPB) attacks (Lorio 1973; Coulson et al., 1974; Belanger et al., 1979; Hicks et al., 1978). Vigorous pine trees resist bark beetle attacks more than nonvigorous ones. Thus, the improvement of tree and stand vigor through silvicultural practices has been recommended as a means of reducing the risk of SPB infestations (Belanger and Malac 1980, Nebeker et al. 1985). However, tree vigor estimation is difficult, time-consuming, and often times subjective. Hence, the search for a simple, inexpensive, and reliable method for assessing tree vigor is desirable not only in terms of making better pest management decisions, but also in determining silvicultural options for stand improvement and management. Although diameter growth, stem growth per unit of leaf area (Waring et al., 1980), and leaf area-sapwood area ratio (Blanche et al., 1985) have been satisfactorily used in tree vigor assessment, they are more indicative of past performance (vigor history) than current vitality. Vigor comparisons of trees of different ages that grow on areas of varying site quality are problematic. We proposed to resolve this problem using stem electrical resistance (SER) as an integrating

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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variable for physiological vigor, the rationale being that SER functionally reflects the current ionic or nutrient, moisture, pathologic, and stress conditions of trees as well as growth activities (Kitching 1966; Polozhentsev and Zolotov 1970; Shigo and Shigo 1974; Shortle et al., 1977; Blanchard and Carter 1980; Blanchard et al., 1983; Piene et al., 1984; Tippett and Barclay 1987).

The specific objectives of these studies were to: (1) determine if site index influences SER in loblolly pine (*Pinus taeda* L.); (2) determine how SER is related to tree growth and environmental factors; and (3) describe the seasonal pattern of SER in loblolly pine and to relate to known phenological events.

Materials And Methods

Stand Selection and Description

Twenty-eight loblolly pine plantations were selected in six east-central Mississippi and west-central Alabama counties. Fourteen of these were from the upper coastal plain, two from the Pontotoc Ridge (Ripley formation), five from the Tombigbee sand-gravel (Eutaw formation), and five from the interior flatwoods (Porter's Creek clay). These stands ranged from 21 to 26 years old with dbh ranging from 15.5 to 28.7 cm and had an average stand density of 1,284 trees/ha. Site indices at age 25 ranged from 14 to 28 m (46-92 ft). These same stands are currently being used for nutrition-productivity studies at Mississippi State University.

Core Sampling and SER Measurements

Three trees representing three crown classes (dominant, intermediate, and overtopped) were sampled from each stand. From each tree, two cores were extracted at right angles to each other at breast height. SER was obtained from the north and south sides of the stem with a field of ohmmeter (Osmose Shigometer model OZ-67). This was accomplished by horizontally inserting the stainless steel probe pins (mean pin separation was 1.8 cm) with one pin directly above the other, through the bark, and into the outer xylem. The pins were cleaned with 80 percent ethanol between insertions. Since electrical resistance is known to vary seasonally (Fensom 1963; Newbanks and Tattar 1977; Davis et al., 1979), the SER measurements and core sampling were done on two clear days in July (1st and 2nd).

Growth Measurements

Xylem radial increment for the last year and the last 5 years were measured from the cores with a microcaliper under a dissecting microscope. The same cores were then reacted with diazotized benzidine dihydrochloride for sapwood-heartwood differentiation (Blanche et al., 1984), after which the sapwood area was determined. Relative xylem area growth was expressed as a percent of last year's xylem area growth over sapwood area. Data were analyzed through analysis of variance, correlations, and regressions.

Seasonal Measurements of SER

Six plots, ranging in mean site index (age 25) from 21 to 33 m, were selected in Winston and Oktibbeha counties, Mississippi. Five trees were utilized on each plot, and they ranged in dbh from 24.13 to 36.58 cm, in height from 18.9 to 26.8 m, and in age from 28 to 47 years. Plots were

visited at approximately 30-day intervals on mornings. Measurements obtained were air temperature and four SER readings taken at dbh, approximately 90 degrees apart.

SER in Relation to Xylem Growth and Environmental Factors

Two loblolly pine stands (a 27-year-old on an upland site and a 24-year-old on a bottomland site) were monitored during the growing period (May to October) for SER, air temperature, soil moisture, and temperature. Sample trees consisted of 10 dominant, 10 intermediate, and 10 overtopped from each stand. Two core samples were extracted at right angles to each other from each tree at dbh at the end of the growing period (November 15). Xylem radial increment for the current year was measured from each core, and the corresponding xylem area increment was calculated. Data were analyzed through regression using linear and nonlinear equations.

Results And Discussion

SER and Site Index

SER was not significantly affected by differences in site index (Table 1). This was true for all crown classes. Although SER appeared to be independent of site index, it was effective in detecting crown differentiation, especially between overtopped and dominant individuals. Similar relationships between SER and crown class were observed in white pine (P. strobus L.) (Kostka and Sherald 1982) and oak (Quercus spp.) (Wargo and Skutt 1975). Since age and height of dominant and codominant trees are directly involved in site quality determination, our results imply that SER is independent of age and height, which makes SER a very useful measure of tree vigor for comparative purposes. However, depth of tissue probed must be constant for this implication to be valid (Tippett and Barclay 1987). Because SER did reflect the crown differentiation and conditions of the individual trees, any factor affecting crown competition is bound to influence SER. Evidence for this was found by Smith et al. (1976) who reported that trees released from crown competition through thinning had lower SER than nonreleased trees.

Crown Class and Potential Measures of Vigor

The classic crown classification was used in this investigation as the standard measure of vigor for the purpose of comparing other potential measures of vigor. Potential measures of vigor closely agree with crown differentiation (Table 2). All potential measures of vigor but one corresponded to differences in crown class. The intermediate crown class was distinguishable from the dominant using the ratio of last year's xylem area growth and sapwood area, but the overtopped was no different from neither the dominant nor the intermediate. These may be due to an increasing level of crown competition currently being experienced by the intermediate class, which may eventually drive this class to an overtopped condition. Unexpectedly, the ratio of last year's xylem area growth to sapwood area was not effective in distinguishing the three crown classes. The relatively lower ratio for the intermediate versus the overtopped trees was unusual, and we could not offer any explanation for this.

Relationship of SER with Tree Growth Characteristics

Last year's xylem area growth (XAG1) is inversely related to stem electrical resistance (Table 3). The power ($Y = aX^b$), logarithmic (Y = a + b

Table 1. Stem electrical resistance of crown classes in relation to site index.

Crown class	Site index classes (at age 25) 12-15m	18-21m	24-28m
	---------------- K ohm ----------------		
Overtopped	34.37 a[1]	29.26 a	35.60a
Intermediate	28.25 ab	20.94 b	22.90ab
Dominant	16.63 bc	12.89 c	17.10 bc

[1] Numbers followed by the same letters in a column are not statistically different at the 95 percent level of significance. There were no significant differences among site index classes within each crown class.

Table 2. Potential measures of tree vigor in relation to crown classes.

Measures of vigor	Crown class Overtopped	Intermediate	Dominant
Stem electrical resistance, K ohm	31.59($\pm$3.11)[1]	21.96($\pm$1.96)	13.82($\pm$1.70)
Last year's xylem area growth, cm^2	3.40($\pm$0.71)	6.06($\pm$1.30)	17.87($\pm$2.91)
Last 5 year's xylem area growth, cm^2	24.57($\pm$3.98)	39.97($\pm$6.76)	90.52($\pm$13.42)
Last year's xylem area/ sapwood area, percent	3.15($\pm$0.46)	2.67($\pm$0.38)	4.10($\pm$0.54)

[1] Values in parentheses are confidence intervals at 95 percent.

n X), and the reciprocal (Y = a + b/X) functions provided a better explanation of the variation in last year's xylem area growth in relation to the variation in stem electrical than the linear function (Y = a + bX). All the growth characteristics were inversely related to SER (Table 4). The ratio of last year's xylem area growth to sapwood area (XASA) was the growth characteristics most poorly correlated with SER (r = -0.22), a finding that was not expected given that this ratio is the basis of the model of host resistance to bark beetle attacks (Waring and Pitman 1980). The correlation between SER and dbh (r = -0.68) is comparable to those obtained

Table 3. Relationship of last year's xylem area (y) and stem electrical resistance (x).

Function	a coefficient	b coefficient	Corr. coef. (r)
$y = a + bx$	21.29	-0.54	-0.64
$y = a + b(\ln x)$	48.36	-12.29	-0.72
$y = a + b/x$	-2.00	207.72	+0.72
$y = ae^{bx}$	25.24	-0.06	-0.66*
$y = ax^{b}$	477.27	-1.43	-0.72*

* The correlation coefficient (r) in nonlinear regression is not as meaningful as the index of fit.

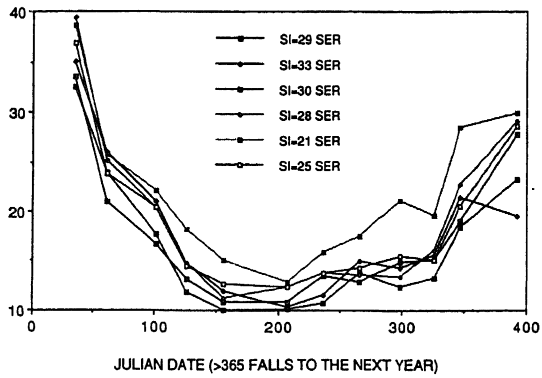
Table 4. A correlation matrix of stem electrical resistance (SER), diameter at breast height (dbh), last year's xylem area growth (XAG1), last 5 years' xylem area growth (XAG5), XAG1 over sapwood area (XASA), and sapwood area (SA).

Variables	SER	DBH	XAG1	XAG5	XASA	SA
SER	1.00	-.677	-.615	-.606	-.219	-.634
DBH		1.00	.852	.853	.232	.982
XAG1			1.00	.955	.623	.877
XAG5				1.00	.535	.874
XASA					1.00	.241
SA						1.00

from different species such as oak (Wargo and Skutt 1975), red maple (Acer rubrum L.) (Carter and Blanchard 1978), sugar maple (A. saccharum Marsh.) (Newbanks and Tattar 1977), and lodgepole pine (P. contorta spp.) (Cole 1980). Of all the characteristics, dbh was the most highly correlated variable with SER. This could be attributed to the generally thicker phloem layer in larger trees providing greater depth of tissue probed. Tippett and Barclay (1987) found that electrical resistance of healthy tissue varied with both the depth of tissue probed and water status of stems. Also, Carter and Blanchard (1978) reported that phloem thickness is highly correlated with SER (r = -0.92), and they demonstrated that the phloem, with its associated cork and vascular cambia, offered the least resistance to electric current in stem. Under other circumstances, however, this factor may be overshadowed by large moisture and temperature differentials, thereby complicating the interpretations of resulting SER measurements.

easonal Pattern in SER

Monthly measurements of SER on dominant trees from six plots with varyng site indices revealed a definite seasonal pattern (Fig. 1). The patern was the same for all site indices. These seasonal changes in loblolly ine SER appeared associated with growth phenological events and seasonal hanges in air temperature. For instance, the sharp decline in SER (Fig.) during the 1st week of March coincided with the start of elongation of verwintering buds. The generally lowest SER values were observed in May, une, July, and August, coinciding with the period of most active growth nd translocation. Axial elongation rates of loblolly in this area peak in id-April, first weeks of May, June, July, and August, corresponding with he first, second, third, and fourth flushes (Griffing 1969). Stem elecrical resistance began to increase slowly in late September coinciding ith leaf fall, and then a rapid increase in mid-November, coinciding with he first frost in this area which appeared to signal the onset of dormany. SER then remained high during the dormant period (winter). These observations suggest that SER may be a good measure of the general metabolic activities of a tree at any given time. Likewise, it reflects the overall water status of the tree, which is the medium of ion and other food transport. Such seasonal changes also suggest that tree vigor comparisons can only be valid if SER measurements were taken during the same time frame.



igure 1. Monthly stem electrical esistance (K ohm) readings on lobolly pine trees from stands of arying site indices.

SER and Environmental Variables

SER was inversely related to all the environmental variables except soil moisture, which was positively correlated or uncorrelated with SER of bottomland trees but negatively correlated with SER of pland trees (Table 5). Air temperature was the most highly and consisently correlated environmental variable with SER for both sites and crown lasses. This may explain the high degree of seasonality of SER. The positive correlation between SER and soil moisture of the bottomland site sugests that occasional flooding causes stress conditions in trees resulting n less cambial and ionic activities, hence, higher SER values. Electrical esistance has been demonstrated to be a reliable indicator of stress in orest trees (Wargo and Skutt 1975).

ER and Vigor Rating

SER can be utilized to classify trees in a stand in to either low or igh vigor classes. Since SER was shown to be independent of site index, t is feasible to rate individual trees from different stands of comparable ge provided times of sampling do not vary significantly. If the trees rom the 28 stands were classified as either low or high vigor using the eneral SER mean of 22 K ohm as the dividing line, 96, 57, and 11 percent f the dominant, intermediate, and overtopped, respectively, would fall uner the higher vigor category. This simply means that not all the overtoped trees are necessarily of low vigor, which further suggests that some

Table 5. The relationships (indicated by correlation coefficient, r) between stem electrical resistance of loblolly pine of different crown classes from two sites, and air temperature, soil temperature, and soil moisture.

Environmental factors	Stem electrical resistance					
	Dominant		Intermediate		Overtopped	
	Bottom	Ridge	Bottom	Ridge	Bottom	Ridge
	r					
Air temp.	-0.67	-0.82	-0.95	-0.96	-0.97	-0.98
Soil temp.	-0.93	-0.49	-0.88	-0.64	-0.83	-0.54
Soil moisture	+0.58	-0.54	+0.05	-0.10	+0.42	-0.76

overtopped trees are able to adjust to a limiting environment and to maintain activities above compensation point. It should be interesting to compare how overtopped trees of high and low SER respond to release.

The separation of trees in a stand as either low or high SER, using the average stand SER as the dividing line, has been suggested (Shortle et al., 1979; Kostka and Sherald 1982). The problem with this scheme is that it automatically classifies half of the trees as low vigor. To alleviate this problem, a finer classification involving more classes may be developed. This could be readily done by dividing the range of SER values into the desired number of classes. Although measuring SER of individual trees for thinning is not practical on a commercial scale, this can have great utility in eliminating subjectivity when imposing experimental treatments. SER has been used as a guide to thinning sugar maples (Shortle et al., 1979).

Conclusions

1. SER is capable of separating low vigor from high vigor loblolly pine trees and is independent of site index.

2. SER changes with season and is related to phenological events in loblolly pine and seasonal changes in temperature.

3. SER is inversely related to radial growth, air and soil temperature, and, to a certain extent, soil moisture.

4. SER can be an effective, inexpensive, and simple method of rating individual tree vigor.

Acknowledgments

Journal contribution No. TS-7639 of the Mississippi Agricultural and Forestry Experiment Station. This study was supported by the Integrated Pest Management Research, Development and Applications Program, Pineville,

LA; USFS Grant 19-82-023, the Mississippi State University and Mississsippi Agricultural and Forestry Experiment Station. We greatly appreciate the reviews by Drs. Keith Belli, Alexander Friend, Bob Karr, and Tom Monaghan of the Department of Forestry, Mississippi State University. Their comments and suggestions vastly improved this manuscript.

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THE EFFECT OF ACID RAIN AND OZONE EXPOSURE ON GROWTH PARAMETERS OF SHORTLEAF PINE [1]

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Abstract. Four open-pollinated families of shortleaf pine were grown in 24 open-top chambers in the South Carolina Piedmont. Measurements of total height and diameter were made every 6 weeks since exposure to three levels of acid rain (pH 3.3, 4.3, and 5.3) and four levels of ozone (charcoal filtered, ambient, 1.7 x ambient, and 2.5 x ambient). Aboveground biomass and leaf area measurements were made on seedlings that were thinned in fall 1988 and 1989. After 16 months exposure, trees exposed to pH 3.3 rain were significantly taller and larger in diameter than those in lower acidity treatments; however, there were no significant differences in biomass components. Trees exposed to the highest ozone (O_3) level (2.5 x ambient) were smaller in diameter, height, biomass components, and leaf area than the lower O_3 exposures. However, the differences were only significant between the 1.7 and 2.5 x ambient exposures, indicating a compensatory effect near the 1.7 level and a negative threshold exposure effect between 1.7 and the 2.5 x ambient treatment.

Introduction

The productivity of southern e forests is limited by a number environmental factors. The roles moisture (excess or deficit), nigen (N), and phosphorus (P) in ecting pine growth are well docuted. Other environmental factors, ., acidic deposition and ozone), may also affect growth of thern pine species (Stone and lly 1974; Phillips et al., 1977). magnitude and extent that these factors may limit forest growth are presently unknown.

Plant response to acidic deposition can result from either direct or indirect effects of acidic precipitation. A direct effect that has implications for tree growth is leaching of nutrients from foliage. The rate of mineral leaching from foliage has been positively correlated with acidity of simulated acidic rain (Fairfax and Lep 1975, Wood and Bormann 1975). Foliar injury to pine seedlings exposed to simulated acidic rain in controlled studies has also been reported (Wood and Bormann 1977; Shafer et al., 1985).

Indirect effects of acidic deposition on tree growth might result from modification of rhizosphere chemistry and flora. Increased

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aper presented at Sixth Biennial thern Silvicultural Research Conence, Memphis, TN, Oct. 30-Nov. 1990.

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rates of N and sulfur (S) deposition from acidic rain may certainly affect tree growth. Controlled studies with pine seedlings indicate that the pH of simulated rain can alter the number of mycorrhizal roots (Shafer et al., 1985).

Ozone has been present throughout the Southeastern U.S. for the past 20 to 30 years at levels that have been shown to reduce growth of southern commercial tree species in laboratory experiments (Kress and Skelly 1982; Kress et al., 1982). Therefore, O_3 must be suspected as a possible factor in reducing forest productivity below its potential. Ozone has also been identified as the most important atmospheric pollutant affecting agriculture because of its well-documented impact on crop species, e.g., peanuts, soybeans, tobacco, and cotton (Heck et al., 1984) at current ambient concentrations, and its ubiquitous occurrence across the Southeast.

Objectives

The intensive field investigations described herein were designed to be supportive of other research planned by the Southern Commercial Forest Research Cooperative. Extensive background information and rationale for this research are contained in Marx et al. (1985). The following questions were specifically addressed in our intensive field studies: (1) what are the functional relationships between acid rain and aboveground growth parameters for open-pollinated shortleaf pine (*Pinus echinata* Mill.) families? and (2) what are the functional relationships between O_3 dose and aboveground growth parameters for open-pollinated shortleaf pine families?

Methods

A range of acidic precipitation treatments was utilized in a factorial arrangement with O_3 concentrations (Table 1). The approach involves the study of plant responses over a range of acidic precipitation and O_3 concentrations. Artificial acid rain treatments ranged from near-"natural" rainfall to acidity near the maximums recorded for this area. Carbon-filtered air chambers which result in low O_3 concentrations were used as the O_3 control treatments.

Table 1. Experimental design for Clemson Experimental Forest acid rain/ozone study site.

Factor	Number
Ozone treatments	4
Acid precipitation treatments	3
Replication	2
Total chamber plots	24

Seedlings from four shortleaf pine open-pollinated families were double ransplanted into the chamber plots. Two of the families were from the uke Forest while the other two were from the Clemson Experimental Forest. he seedlings were germinated in Spring 1987 and transplanted into the hambers in November 1987. The chambers were divided into quadrants with eedlings from two families in opposite quadrants and the other two famil- es in the other two quadrants. This yielded 48 seedlings per quadrant (2 amilies x 12 replications x 2 for survivability). Seedlings were planted).5-cm apart in an arrangement that produced equal numbers of each family t each thinning. Each family genotype received a color code and all fam- lies in each chamber were planted in exactly the same planting scheme to educe variation and errors due to family identification. As the seedlings rew, they were destructively sampled in the Fall to allow the residual eedlings optimum growing space. At the beginning of the first exposure, he double planted seedlings were thinned to one seedling. The schedule hen called for the removal of 16 of 24 seedlings per quadrant after the irst year, four of eight after the second, and a final harvest of the re- aining four per quadrant at the end of the third year. The results re- orted herein reflect this second harvest.

Three acidic precipitation treatments were applied in this study. The H of the simulated rain treatments was 5.3 (control), 4.3, and 3.3. These H levels were chosen to span the average pH of rainfall in South Carolina. cidic solutions were prepared by adjusting the pH of deionized water con- aining selected background ions (Shafer et al., 1985) with a 1-N mixture f sulfuric and nitric acids (70 meq $SO_4^{=}$ :: 30 meq NO_3^-). Final [H^+] of ach solution was determined with a pH meter.

Simulated rain was applied through a stainless steel solid cone nozzle ounted on a bracket in the rain exclusion cover in each chamber. Each ozzle was operated at 10 psi pressure to minimize variability. Total vol- me of deposition was based on the average rainfall occurring in the study rea taken from a 30-year average rainfall record accumulated by the NOAA eather Substation at Clemson University (summary obtained from the Okla- oma Climatological Survey). Rainfall events occurred on a regular basis nd depended on the weekly average for that time of year. Acid rain depo- ition was administered year-round, paying careful attention to local win- er weather conditions to preclude damage to seedlings and distribution ardware due to freezing temperatures.

The most thoroughly tested and widely accepted exposure facility for esting O_3 effects on plants under field conditions is the open-top chamber Mandl et al., 1973; Heagle et al., 1979; U.S. EPA 1987a; 1987b). These hambers are cylinders constructed with aluminum frames covered with clear lastic film. The chambers in this experiment were 4.6 m in diameter and .6-m tall with frusta at the top so the top orifice was reduced to 3.1 m n diameter. Some chambers were nonfiltered (particulate filter only) per- itting the use of ambient O_3 as a baseline for developing additional dos- s. Different doses were obtained by either adding O_3 at various concen- rations to the ambient O_3 load or by filtration to reduce the ambient O_3.

Ozone was dispensed to chambers following the basic techniques utilized n the NCLAN program (Heagle et al., 1979). Griffin O_3 generators were sed to generate O_3 for treatments receiving above ambient concentrations

of O_3. Ozone was dispensed through needle valves to allow control over the quantity dispensed. Delivery of O_3 to the chambers was through Teflon™ tubing that runs from the site building to the fan box, where it was drawn into the air stream entering the chamber. Ozone was added to 12 chambers resulting in the following O_3 treatments:

(1) charcoal-filtered ambient air (CF, as control);
(2) ambient (nonfiltered) air;
(3) 1.7 times ambient; and
(4) 2.5 times ambient.

Ozone was added daily on a proportional basis to ambient O_3 for 12 hr per day, from March 1st to October 31st, and 9 hr per day from November 1st to February 28. Ozone production was turned on by computer control whenever the ambient O_3 was at or above 15 ppb. The control system had a built-in cutoff when the ambient O_3 concentration reached 150 ppb to insure that no enhanced concentrations exceeded 375 ppb. Ozone treatments were administered year-round. The proportional addition to ambient during the day (above 15 ppb) assured O_3 additions only under environmental conditions most conducive to elevated ambient O_3.

At the end of the 1989 growing season (October), individual trees were cut at ground level and removed for component sampling. Root collar diameter and total height were measured and separate determinations were made of dry weight of the foliage, mainstem and lateral branches. Tree height was measured using a metric scaled ruler. Measurements were made from the soil surface to the terminal bud of the main shoot.

Trees were removed one at a time and immediately weighed to determine green weight using an electronic balance. The tree was then separated into component parts which were weighed green. A sample of each component was then weighed and percent moisture was determined by drying the sample for 72 hr at 70°C. This percent moisture was then used to determine dry weight of the originally measured green weight component.

The leaf area of each harvested tree was determined by randomly sampling six complete fascicles from each tree and combining them by chamber and family for a total of 24 fascicles. This material was measured by volume displacement and the surface area calculated by the method described in Johnson (1984) and modified by Shelburne (1988). Specific leaf area (cm^2/gm dry weight) was determined by drying the needles in the above sample at 70°C for 48 hr. The surface area determined above was divided by this dry weight value and the dry weight biomass of each individual tree was multiplied by this family specific leaf area value to determine each tree's total leaf area.

Analysis of variance was used on the various parameters to determine the effect of acid rain and O_3 treatment. In the case of height and diameter where initial height and diameter of each tree was known, analysis of covariance was done using these initial values as the covariates.

Results

The effect of acid rain treatment on total height and diameter after 16 months exposure showed no significant difference between treatments although the trend indicated that trees exposed to more acidic conditions were taller than those exposed to rain of lower acidity. This trend was significant, however, when analysis of covariance was done on incremental height and diameter (Table 2). In this analysis, trees exposed to the highest level of acidity (pH 3.3) had significantly greater height and diameter increment ($p < 0.05$) as compared to those at the lowest level of exposure (pH 5.3).

Table 2. Effect of acid rain on incremental height* and diameter* growth after 16 months exposure.

	Height increment	Diameter increment
	(cm)	(mm)
	Least square means	
pH 3.3	105.4a[1]	23.7a
pH 4.3	96.2ab	22.3ab
pH 5.3	91.0 b	20.9 b

[1] Least square means (within columns) followed by same letter are not significantly different at the 0.05 level (t-test).

* Initial height and diameter used as covariate, respectively.

The effect of O_3 exposure after 15 months on both total height and diameter along with incremental growth showed no significant effect (Table 3). However, it should be noted that there was a trend of reduced height and diameter at the highest level of ozone exposure as compared with the three other levels of exposure.

Biomass data reflected the same trends as the above data when acid rain exposures were analyzed (Table 4). In general, the component biomass portions (leaf, lateral stems, and mainstem) and the total aboveground biomass showed no significant difference due to the effect of acid rain; however, the trend showed an increasing amount of biomass for the whole tree due to higher levels of acidity (pH 4.3 and 3.3) as compared with the lowest level (pH 5.3).

Ozone exposure effects on biomass did, however, show a significant effect in that the highest level of O_3 exposure produced trees which had significantly less biomass in all components as compared to trees at the next highest level of exposure (Table 5). It should be noted, however, that the significant difference existed only between these two highest exposures. The increasing trend towards greater biomass at the 1.7 x ambient level of exposure and the large relative decrease in biomass at the highest level (2.5 x ambient) is responsible for this significant difference.

Table 3. Effect of ozone on incremental height* and diameter growth* after 15 months exposure.

	Height increment	Diameter increment
	(cm)	(mm)
Ozone level	Least square means	
Charcoal-filtered	96.7a[1]	22.7a
Ambient	97.2a	23.1a
1.7 x ambient	105.5a	22.5a
2.5 x ambient	90.9a	20.8a

[1] Least square means (within columns) followed by same letter are not significantly different at the 0.05 level (t-test).

* Initial height and diameter used as covariate, respectively.

Table 4. Effect of acid rain on aboveground and component biomass after 16 Months.

	Biomass			
pH	Tree	Leaf	Laterals	Main stem
	(g dry weight)			
5.3	252.8a[1]	137.1a	34.6a	81.1a
4.3	315.0a	166.9a	42.2a	106.0a
3.3	314.4a	163.8a	44.8a	105.7a

[1] Means (within columns) followed by same letter are not significantly different at the 0.05 level (Tukey's test).

The effect of acid rain treatment on leaf parameters (specific leaf area, individual leaf area, total tree leaf area, and needle length) was not significant (Table 6). Likewise, the effect of O_3 exposure was not significant on specific leaf area and individual leaf area. However, it was significant on total tree leaf area between the two highest levels of O_3 exposure with the highest exposure having significantly lower area (Table 7). This result might be expected since the biomass values of the leaves from the previous analysis were multiplied by their respective specific leaf area values to derive the total tree leaf area value.

Table 5. Effect of ozone on aboveground tree and component biomass after 15 months exposure.

Ozone level	Biomass			
	Tree	Leaf	Laterals	Main stem
	(g dry weight)			
Charcoal filtered	319.8ab[1]	168.2ab	43.5ab	108.2ab
Ambient	277.6ab	151.0ab	39.9ab	86.7ab
1.7 x ambient	357.1a	186.4a	49.3a	121.4a
2.5 x ambient	221.8 b	118.3 b	29.6 b	74.0 b

[1] Means (within columns) followed by same letter are not significantly different at the .05 level (Tukey's test).

Table 6. Effect of acid rain on leaf parameters (16 months exposure).

pH	Specific leaf area	Leaf area	Total tree leaf area	Needle length
	(cm^2/g)	(cm^2)	(m^2)	(mm)
5.3	167.4a[1]	7.1a	2.3a	95.4a
4.3	169.3a	7.1a	2.8a	97.7a
3.3	173.5a	7.1a	2.8a	96.7a

[1] Means (within columns) followed by same letter are not significant at the 0.05 level (Tukey's test).

Discussion

The increased height and diameter growth in those trees exposed to higher levels of acidity are probably due to the increased amount of N made available through the treatment and a masking of any measurable deleterious effect of the high acidity. The increased level of this nutrient on sites which are generally deficient leads to a fertlizer effect which essentially promotes greater growth. Therefore, at this point in the study, there were no obvious negative effects due to the increased acidity of the applied rain. However, the short-term nature of this study precludes any generalization about the possible long-term effects on soil chemistry which might alter tree nutrition.

With respect to O_3, the negative effects of the highest level of exposure were certainly evident. However, except for needle length, there were

Table 7. Effect of ozone on leaf parameters (15 months exposure).

Ozone level	Specific leaf area	Leaf area	Total tree leaf area	Needle length
	(cm^2/g)	(cm^2)	(m^2)	(mm)
Charcoal filtered	171.7a[1]	7.3a	2.9ab	99.7a
Ambient	171.9a	6.9a	2.6ab	96.1ab
1.7 x ambient	171.1a	7.3a	3.2a	98.5ab
2.5 x ambient	165.5a	6.9a	2.0 b	92.1 b

[1] Means (within columns) followed by same letter are not significant at the 0.05 level (Tukey's test).

no significant differences between the charcoal-filtered or ambient treatment and the highest O_3 treatment. Although the overall trend indicated less growth response with increasing levels of ozone, this trend was confounded by the increase in growth at the 1.7 x ambient treatment. As noted above, the significant differences noted in biomass and total tree leaf area were only noted between this level of treatment and the highest level (2.5 x ambient) which exhibited a great reduction in all these parameters. The significance of the compensatory growth at this intermediate level of O_3 exposure can not be fully explained at this time. Other studies in the Southern Commercial Forest Reseach Cooperative have noted this effect in other southern pine species. Tingey and Taylor (1982) have hypothesized that this may be the activation of a direct or indirect compensatory mechanism in response to the stress. Likewise, there may be reallocation of carbon within the plant to the aboveground portions in order to compensate for the premature senescence of needles which is a common O_3 effect seen in this study. A concurrent analysis of the carbohydrate status of the trees over time which is being done in this study along with a companion study on root/shoot ratios of potted trees which were placed in the chambers should provide information regarding carbon allocation patterns.

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BELOWGROUND CHANGES IN LOBLOLLY PINE AS INDICATORS OF OZONE STRESS [1]

Patricia Faulkner, Michele M. Schoeneberger and Lance W. Kress [2]

Abstract. Ozone (O_3) is considered a contributing factor in the decline of forests in the U.S. Carbon allocation is altered in plants exposed to O_3 with aboveground portions usually retaining a greater share of assimilates than the root system. Therefore, monitoring root structure and function may provide early indicators of pollutant stress. The challenges lie in overcoming current methodological constraints on accurately measuring these parameters. Seedlings planted in open-top chambers were exposed to three O_3 treatments [charcoal filtered (CF), and 1.5 x, and 3.0 x ambient air] for two growing seasons (1987, 1988). Taproot cores were extracted at the end of the 1987 season, and whole root systems were excavated during the final harvest in December 1988. Compared with the CF treatment, there was little change in root biomass in the 1.5 x ambient air exposure, but significant biomass reduction in the 3.0 x ambient treatment. Total available carbohydrates of the carbon-demanding fine roots were dramatically reduced at the highest O_3 dosage, primarily due to starch losses. In contrast, percent nitrogen was significantly increased. No detectable differences were found among the three O_3 treatments for ectomycorrhizal counts or rhizosphere soil analyses.

Introduction

Ozone (O_3), a photochemical oxidant, is considered a contributing factor in the decline of forests in the United States (Johnson and Siccama 1983, NAPAP Report 1990). Ozone injury is often difficult to detect at chronic ambient levels for plants exposed under experimental conditions (Mooney and Winner 1988). No visible symptoms may be present, especially at the early stages of exposure. A study of physiological processes within the trees seems to provide the key to understanding initial plant responses to O_3 stress. Carbon allocation is altered in plants exposed to O_3 (Cooley and Manning 1987, Mooney and Winner 1988). A greater reduction in belowground biomass compared with aboveground biomass was reported for 16 of 20 plant species exposed to O_3 (Cooley and Manning 1987 review article). Interpretation using only aboveground biomass in two of these studies would have lead to the erroneous conclusion that O_3 had no effect or perhaps even a beneficial effect on the plants, despite the significant suppressions that occurred belowground (e.g.,-40 and -32 percent for parsley and carrot, respectively).

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Impacts of O_3 on carbon allocations allocation are important in deter-ning plant quantity (i.e., biomass) and plant quality (i.e., the tree's ergy reserves in the form of available carbohydrates). Suppression of ailable carbohydrates in the belowground component may reduce mycorrhizal fection (Marx et al. 1977), nutrient availability (Jayachandran et al. 89), disease resistance (Matson and Waring 1984), and longevity of fine ots (Marshall and Waring 1985), thus lowering nutrient and water uptake d resistance to secondary stresses. Given the importance of the root stem in determining a tree's performance and survival over its lifetime, is important to have an understanding of how both belowground and above-ound components react to pollutant exposure. Unfortunately, root meas-es are laborious and expensive. Root harvesting impacts to the above-ound portions of the tree must be minimized to preserve the integrity of e experiment. However, this may compromise the quality of root measures. e challenge lies in overcoming these constraints on obtaining meaningful ot measurements.

A field trial was established to test experimental methodologies and otocols for use in Southern Commercial Forest Research Cooperative CFRC) field studies. The study provided the opportunity to examine root rvesting techniques and the usefulness of these data to describe O_3 in-ry to loblolly pine (Pinus taeda L.). The main objectives of this paper re to determine the effects of O_3 on belowground biomass and biochemis-y, and to determine the usefulness of subsampling versus whole plot root rvesting for obtaining meaningful root measures.

Methods

udy Site and Treatments

The study site was located in Durham, North Carolina, on a portion of e Duke Experimental Forest. The soil was a moderately well-drained Hel-a series (clayey, mixed, thermic, Aquic Hapludult), with an underlying B_t restrictive clay layer at 30.5 cm. This clay layer restricted rooting pth. The presence of this layer, along with fall precipitation prior to ot sampling, resulted in saturation to the soil surface. Implications of ese soil factors will be discussed with the data results.

Seedlings from three open-pollinated loblolly pine families (8-80, 103 and 8-130) were selected to represent a range of ozone sensitivity sed on seedling trials (Weir 1977). Twelve-week-old containerized seed-ngs from the selected families were planted on previously cleared and ro-tilled circular plots in June 1986. In March 1987, 3-m diameter open-top ambers were constructed over the planted plots. Ozone and acid rain eatments were assigned in a factorial arrangement on two blocks of six-en plots each. For the purpose of this inquiry, only results from three treatments are presented (12 chambered plots, 2 replications/O_3-acid in treatment), those being: 1.5 x and 3.0 x ambient air O_3 levels and arcoal filtered (CF) representing cleaned air with a background of ap-oximately 25 ppb O_3. The seedlings were exposed for two growing seasons 987 and 1988). Details of exposure procedures are found in Kress et al. 989).

Study Measurements: 1987 Harvest

At the end of the first exposure season (March-December), seedlings in the selected chambers were thinned and shoots retained for biomass measures on stem, branch, and foliage components. Root cores from three seedlings/plot for each chamber were collected using a 10.2-cm diameter corer placed over the severed mainstems of the harvested trees. Soil cores, collected from extra plots and not used in this study, were placed back in the treatment plot holes to minimize damage incurred from subsampling. The sample cores were coarsely washed with tap water using a hose and spray nozzle. The root sample collected (taproot and attached laterals) was cleaned using deionized water and paint brushes. A subsample of laterals less than 2 mm in diameter (approximately 1-2 g dry weight) was collected and analyzed for available carbohydrate analysis (Schoeneberger et al., 1990). The remaining taproot portion and associated laterals were oven-dried to 70°C and weighed.

1988 Harvest

At the end of the second exposure season (March-November), a complete aboveground harvest was done for biomass measures. The removal of all top portions provided the opportunity for a complete root system excavation. To facilitate the root collection, chambers were disassembled. A hole was dug along the periphery of each plot, improving access to the soil within the plot. Soil and roots were loosened with a spading fork and root stumps with attached laterals were carefully removed, labelled and composited by family and plot. The remaining root pieces were collected by sieving the soil within each plot (3-m diameter by 25.4 cm deep) through a 12.7-mm mesh screen. These roots were then composited by plot only as family distinctions could not be made. Soil attached to lateral roots on the root stumps was removed using paint brushes. These soil samples, designated as rhizosphere soils, were analyzed for nutrients and enzyme activities by North Carolina State A&T University (Greensboro). Subsamples of fine roots (< 2mm diameter) were collected for ectomycorrhizal examination (i.e., 10 laterals each approximately 5-cm long) and available carbohydrate analyses. The remaining root portions were oven-dried to 70°C, separated into one of three size classes (<2mm, 2-5 mm and > 5mm diameter) and weighed. Biomass is expressed on an ash-free dry weight basis.

Root material that could be identified on a family/plot basis was ground and analyzed for nutrient content at North Carolina State University (Raleigh). Carbohydrate analyses were performed at the USDA-Forest Service Laboratory (Research Triangle Park) utilizing a method modified for loblolly pine material (Schoeneberger et al. 1990). Ectomycorrhizal assessments were made on short root sections with the aid of a dissecting scope. Root tips were categorized by morphotype and expressed on a per-length basis (Grand and Harvey 1982). All data were examined for homogeneity of variance, transformed where necessary, and analyzed using the PC Statistical Analysis System procedure of General Linear Model (GLM) (SAS Institute 1985).

Results And Discussion

ιiomass

Results from the 1987 subsampled root cores indicate that the 3.0 x am- ɔient treatment significantly reduced root growth ($p > 0.10$) as compared ʼith the CF treatment, while the 1.5 x ambient exposure had no effect (Ta- ɔle 1). This subsample, representing only those roots in immediate proxim- ty to the main stem, was comprised primarily of the taproot and may not ıave adequately represented the impact to the laterals and fine roots. ʼhis technique does allow a mid-experiment measure of the belowground ːtructures, but the restricted sampling of smaller roots limits the con- ːlusions concerning O_3 impacts on root systems. Given the high carbon ːemand of the fine root biomass (Reid et al., 1983; Waring and Schlesinger 985; Cairney et al., 1989), it can be hypothesized that this pool would be ːffected to a greater extent than the taproot. Sampling for this pool ːould have been done by collecting between stem samples. This approach ʼould have limited the ability to detect family differences, and also adds ːhe problem of greater disturbance to the remaining seedlings.

Table 1. Impact of ozone on above- and belowground biomass (g) of lob-lolly pine seedlings (1987 n = 54; 1988 n = 14).

Parameter	Ozone exposure 1.5 x ambient	3.0 x ambient
	--- (percent charcoal-filtered) ---	
1987 Harvest[1]		
Total roots[2]	0	-26
Total aboveground[2]	0	-40
1988 Harvest[1]		
Total roots[2]	+9	-48
Root diameter class:		
< 2 mm	-8	-46
2-5 mm	-8	-38
> 5 mm	+17	-51
Total aboveground[2]	+21	-47
Aboveground component:		
Foliage	+18	-55
Stem	+19	-45
Branches	+31	-32

[1] The 1987 root harvest by coring; the 1988 root harvest by whole-plot excavation.

[2] Values calculated from means without separations by diameter class or components.

Total recovered root estimations were possible with the 1988 whole chamber excavations due to restriction of the rooting zone. The B_t clay layer at 25-30 cm and plot preparation (rototilling) both contributed to rooting zone restriction. By excavating the whole plot, 1988 results for total recovered root biomass also indicated that the 3.0 x ambient treatment significantly reduced ($p > 0.05$) root biomass compared with the CF treatment. A similar change was observed in total aboveground biomass (Table 1). Data for the 1.5 x ambient treatment suggest O_3 had a favorable, though nonsignificant, effect on the total recovered root biomass relative to the CF treatment. This trend was similar to that observed for the aboveground biomass. Harvesting by family and size class indicates that this apparent increase in root biomass at the 1.5 x level was in the > 5 mm size class, an increase which most likely occurred within the structural stump portion of the root. This increase was evident for only one of the three families (8-80) (Fig. A.). The smaller roots (< 5 mm) were actually reduced at the 1.5 x ambient treatment (Table 1). This trend is in keeping with the carbon-demand concept discussed earlier. There was an apparent shift of carbon allocation priorities to the aboveground portions when the seedlings were exposed to the 1.5 x ambient treatment. Then at some level of O_3 exposure between 1.5 x and 3.0 x the physiological impact became so great that both the root and shoot growth are reduced.

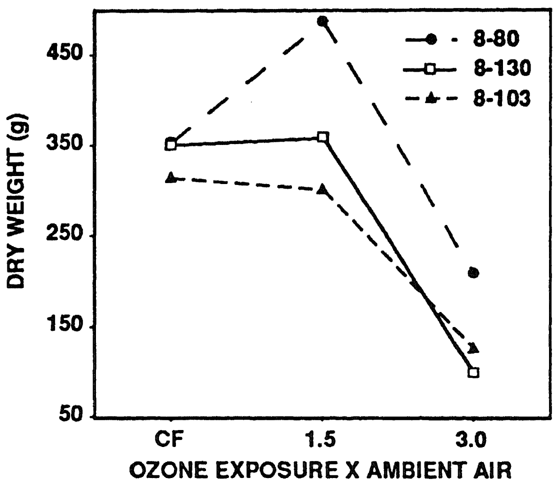

Figure A. Loblolly pine large (> 5 mm diameter) root biomass by family for 1988 harvest.

Available Carbohydrates

Available carbohydrate data were expressed on both a concentration (mg/g) and content (g/total plant component) basis for the 1988 harvest. Carbohydrates were analyzed only for foliage and root samples as these two components represent the "active" portions of a tree's functions (i.e., photosynthesis and water/nutrient uptake). Carbohydrate contents for tissue collected in 1987 could not be calculated because only a subsample was taken that year.

On a concentration basis, fine root available carbohydrates exhibited similar patterns in both 1987 and 1988. Total available carbohydrates (TAC) in the 3.0 x ambient treatment were significantly lower than the CF treatment, particularly for starch (1987: $p < 0.1$; 1988: $p < 0.05$) (Table 2). The 1988 foliage available carbohydrates in the 3.0 x ambient treatment were even lower in starches than the CF treatment while the 1.5 x ambient treatment actually resulted in an increase in this component.

When the 1988 data were examined on a content basis, fine root available carbohydrate reductions occurred for all parameters (Table 3). The reductions averaged 10 percent of the CF treatment at the 1.5 x ambient

able 2. Impact of ozone on available carbohydrate concentration of oblolly pine fine roots and foliage (1987 n = 54; 1988 n =12).

arameter	Ozone exposure	
	1.5 x ambient	3.0 x ambient
	--- (percent charcoal-filtered) ---	
987 Harvest		
Fine roots (< 2 mm)		
TAC [1]	+2	-22
Total soluble sugars	+1	-12
Starch	+2	-28
988 Harvest		
Fine roots (< 2 mm)		
TAC	-5	-17
Total soluble sugars	-6	-8
Starch	-4	-23
Foliage		
TAC	-5	-17
Total soluble sugars	-10	-9
Starch	+21	-64

Total available carbohydrates (starch + soluble sugars).

able 3. Impact of ozone on available carbohydrate concentration of oblolly pine fine roots and foliage for 1988 (n = 12).

arameter	Ozone exposure	
	1.5 x ambient	3.0 x ambient
	-- (percent charcoal-filtered) --	
Fine roots (< 2 mm)		
TAC [1]	-10	-46
Total soluble sugars	-10	-40
Starch	-10	-49
Foliage		
TAC	+19	-64
Total soluble sugars	+14	-60
Starch	+41	-85

Total available carbohydrates (starch + soluble sugars).

treatment and 43 percent at the 3.0 x ambient treatment. Examining both above and belowground data, the available carbohydrate pools were significantly suppressed in both components at the highest O_3 level (3.0 x), while at the lower O_3 level (1.5 x) the available carbohydrates were maintained in the aboveground portions (+41 percent for starch) to the detriment of the belowground (-10 percent for starch). This trend, as that observed in the biomass, is in keeping with the working hypothesis of O_3 stress on plants.

Nutrients

Foliar and total root nitrogen (N) and phosphorus (P) were analyzed for samples collected in 1988 only (Table 4). Based on concentration, root N and P were significantly greater than CF in the 3.0 x ambient treatment at $p < 0.05$ and $p < 0.01$, respectively. Although differences based on content were not statistically significant, root N and P declined with increasing O_3. Significantly higher N concentrations and lower N and P contents were observed in foliage following exposure to 3.0 x ambient O_3. These increases in nutrient concentrations at the highest O_3 treatment are probably the result of lowered carbohydrates and decreased tissue production. The data for the 1.5 x ambient treatment, however, indicate that O_3 may be altering more than just growth. While root N and P content were unchanged by this O_3 level, both foliar N and P content were increased suggesting that nutrient allocation was also being altered. This phenomenon can not be confirmed until a whole-plant nutrient budget is calculated.

Table 4. Impact of ozone on nitrogen and phosphorus concentration (percent) and content (g) of loblolly pine roots and foliage for 1988 (n = 11-12).

Parameter	Ozone exposure			
	1.5 x amb	3.0 x amb	1.5 x amb	3.0 x amb
	(percent charcoal-filtered)			
	Concentration		Content	
Roots				
Nitrogen	+4	+22	-1	-16
Phosphorus	+1	+23	-4	-15
Foliage				
Nitrogen	+4	+26	+19	-42
Phosphorus	+1	+10	+16	-49

Ectomycorrhizae And Rhizosphere Chemistry

No significant differences due to O_3 treatment in total numbers or types of mycorrhizal tips were detected. Mean numbers of total tips were

73, 9.49, and 8.16 per 100 cm long root for CF, 1.5 x and 3.0 x treat-
ents, respectively, with $p < 0.3$. This result is in contrast to the find-
gs in a number of studies that showed a significant impact of pollutant
the ectomycorrhizal component (Meyer et al., 1988; Stroo et al., 1988;
eier et al., 1990). The lack of ectomycorrhizal response to O_3 in this
udy was probably attributable to soil conditions, sampling method and
ming. The saturated soil conditions, as well as, the seasonal timing of
e harvest were not conducive to mycorrhizal initiation or persistence.
addition, the necessity for rapid root extraction (to maintain the in-
grity of the carbohydrate samples) may have resulted in the loss of root
ps. These factors, along with the constraint of limited replication,
ssibly hindered detection of any treatment differences.

Analyses of the rhizosphere soil for chemical status, enzyme activity
d microbial numbers also yielded little in the way of usable information
eddy et al., 1990). Soil organic matter, activities of enzymes and mic-
bial numbers were all greater in the rhizosphere soils as compared to the
lk soil, but there were no statistically significant differences among
e three O_3 treatments examined in this study. As with the mycorrhizal
ta, the saturated soil conditions prior to harvesting may have masked any
fects of the O_3 treatments.

search Implications

Ambient O_3 levels currently occur at levels far below that of the 3.0 x
bient treatment used in this study. As pointed out by Treshow and Ander-
n (1989), and supported by results of this study, the impact of O_3 at
ese high levels results in greatly suppressed biomass accumulation with
ttle obvious effect on assimilate partitioning. At more realistic O_3
ncentrations, such as the 1.5 x ambient treatment, the growth reductions
oveground are not readily evident, though decreased assimilate partition-
g to the belowground is. Examination of root parameters with regards to
omass, available carbohydrates, and nutrient status, suggest that there
n be important, though not readily visible effects of low levels of O_3
.e., between 1.5 to 3.0 x ambient) on loblolly pine seedling performance.
ta at the more biologically relevant 1.5 x ambient treatment were gener-
ly not significantly different from the charcoal-filtered treatment.
wever, the trends indicated assimilate partitioning was favored in the
oveground portion over that of the belowground. Further work should be
ncentrated on understanding tree response at these intermediate levels.
e inconclusive results at the 1.5 x level of O_3 in this study and the
ck of mycorrhizal or rhizosphere chemistry responses also point toward
e inefficiencies of the current root harvesting techniques and schedules.
only one "snapshot" in time picture of the belowground can be obtained,
ere should be an optimization of the timing of both belowground and
oveground data collection. For this study, a harvest in June after
ring root growth and first flush expansion, may have been a more approp-
ate time to assess O_3 impacts. In contrasting subsampling and whole plot
ot excavation, the importance of capturing as completely as possible the
ot systems being sampled becomes evident. When examining total root bio-
ss for the 1988 harvest, data indicated an increase at the 1.5 x ambient
vel. However, when the root data were broken down by sizeclass and fam-
y, it was evident that this increase was merely due to taproot growth in
mily 8-80, and that biomass of the functionally important fine roots had

actually decreased. This impact of O_3 on fine roots at the 1.5 x ambient exposure would not have been evident if only taproot cores or total roots had been examined. As the resolution of the parameter components increases (i.e., total roots to root sizeclasses to family differences within size classes), the understanding of ozone impacts increases.

Acknowledgments

Authors acknowledge assistance of the Southeastern Forest Experiment Station, North Carolina State University, North Carolina State A&T University, and Duke University. This research was supported by funds provided by the Southeastern Forest Experiment Station, Southern Commercial Forest Research Cooperative of the Forest Response Program. The Forest Response Program, part of the National Acid Precipitation Assessment Program, is jointly sponsored by the USDA Forest Service, U.S. Environmental Protection Agency, and the National Council of the Paper Industry for Air and Stream Improvement. This paper has not been subject to EPA or Forest Service policy review and should not be construed to represent the policies of either Agency or of NCASI.

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SITE IMPACTS ASSOCIATED WITH THREE TIMBER HARVESTING SYSTEMS OPERATING ON WET PINE FLATS-- PRELIMINARY RESULTS [1]

W. Michael Aust, Thomas W. Reisinger, James A. Burger, and Bryce J. Stokes [2]

Abstract. Site impacts associated with a conventional rubber-tired skidder, a high-flotation-tired skidder, and a helicopter logging operation were evaluated on wetland sites within the Francis Marion National Forest in coastal South Carolina. Pre- and post-harvest measurements of soil physical properties indicated similarities among all harvest operations, although the relative degree of disturbance differed among systems. Overall, each wet site harvest operation tended to increase soil bulk density and soil mechanical resistance; decrease total porosity, microporosity, macroporosity, and saturated hydraulic conductivity; and increase water levels. Thus, these harvesting operations tended to reduce aeration and drainage on these wet sites.

Introduction

Wet pine flats comprise an extensive and productive wetland forest site type in the Southeastern United States. The proximity of the water tables to the soil surface poses a dilemma for harvesting operations. Harvesting operations on these sites can alter wetland functions, reduce site productivity, and may fail to meet state forestry best management practices, particularly if harvests are conducted during wet soil conditions. Numerous types of equipment mixes have been used to harvest these wet pine flats, including rubber-tired and tracked skidders, cable systems, helicopter sys tems, and even horse and mul logging.

The aftermath of Hurricane Hu go's devastating sweep through coas tal South Carolina mobilized an en ormous salvage effort to recover portion of the blown-down timber. great diversity of harvesting sys tems, both common and unique, wer employed in the salvage. The abur dance and proximity of harvest op erations offered an opportunity fo the examination of soil-site impact associated with the various systems Three of the more common salvag harvest systems were studied: (1 conventional-width rubber-tire skidder; (2) wide-width rubber-tire skidder; and (3) helicopter.

The objectives of this researc project were: (1) to quantify soi and site disturbances resulting fro selected harvesting systems operat ing on poorly drained, pine fla wetland sites on the Francis Mario National Forest; and (2) to documen and describe each study site pric

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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and after harvesting for detailed comparison of soil and site impacts sulting from harvesting.

Previous Research

Most forest managers are aware that harvest machinery traffic has the tential to reduce site quality if harvest operations are poorly planned implemented. Yet the degree and extent of site damage associated with rvest operations are poorly documented (Greacen and Sands 1980; Burger 83; McKee et al., 1985). Gent et al. (1983, 1984) evaluated the effects intensive forest management on the physical properties of Coastal Plain d Piedmont forest soils. In each region, harvesting operations were und to significantly compact soils, and in the Lower Coastal Plain, harsting also decreased soil drainage and aeration. Wimme (1987) examined mpaction of a Coastal Plain site as influenced by soil moisture and conuded that dry soils are relatively immune to compaction by skidder trafc, while moist soils are subject to compaction and wet soils are subject puddling.

Soil compaction and puddling reduce soil aeration, drainage, and peneability, all of which have the potential to degrade site quality (Burger 83; Reisinger et al. 1988). The actual degree of disturbance associated th harvest operations on wet sites can best be evaluated by an examinaon of soil physical properties such as soil bulk density, soil mechanical sistance, soil porosity, hydraulic conductivity, and soil water levels.

Soil bulk density is the mass (oven-dried) of the total soil volume ere volume includes both solids and pores (Danielson and Sutherland 86). Bulk density is commonly used as an indication of soil compaction. avy harvesting machine traffic may compact a soil, resulting in higher lk density values which may result in increased soil strength and deeased pore space and drainage (Greacen and Sands 1980; Gent et al., 1983, 84; McKee et al., 1985).

Soil mechanical resistance estimates shear resistance, or strength, of soil (Bradford 1986). Numerous studies have indicated that soil mechanal resistance values greater than 2000-2200 kPa restrict root growth urger et al., 1988). Cone penetrometers provide a rapid and accepted thod for comparing relative strengths of soils under similar soil moisre and soil structure conditions (Soane et al., 1981; O'Sullivan et al., 87).

Hydraulic conductivity is a measure of soil water movement to plant ots and drainage of water from a soil profile (Aust 1989; Klute and Dirken 1986). Coote and Ramsey (1983) and Culley et al. (1982) concluded that draulic conductivity is one of the better indicators of the long-term efcts of site disturbance upon soil physical properties and plant growth. st (1989) found that ground skidding and helicopter logging methods relted in different rates of hydraulic conductivity, which in turn altered her soil physical and chemical properties. Wimme (1987) evaluated the pact of wet versus dry skidding conditions upon hydraulic conductivity d found reduced rates of soil water movement resulted within the wetter, mpacted area.

Soil porosity is the portion of the soil volume occupied by air and water (Danielson and Sutherland 1986). It is largely determined by the arrangement of solid particles and can be negatively impacted by soil compaction (Greacen and Sands 1980). Total porosity is commonly subdivided into micropores (capillary) and macropores (non-capillary). Macropores allow relatively rapid movement of water and air into and from the soil profile, while micropores retain water and allow little air movement (Danielson and Sutherland 1986). Several harvesting and site impact studies have indicated that soil compaction may not alter total porosity; rather, the ratio of micropores and macropores is altered so that micropores are favored. This alteration decreases water movement and aeration which may reduce plant growth (Burger et al., 1988).

Methods And Procedures

Three types of logging operations were evaluated: a Frankin 105 skidder equipped with 71-cm- (28-inch-) wide tires was used in one operation, while a Franklin 205 skidder equipped with 173-cm- (68-inch-) wide tires was used in another. The helicopter operation was served by a Chinook helicopter, and the logging deck was trafficked by a variety of equipment, including a skidder, a front-end loader, and several tractor-trailer combinations. Harvest impacts within the actual helicopter harvest area were negligible; therefore, only the helicopter deck was evaluated.

Essentially, this research project was composed of three separate "case studies" designed to document soil-site impacts associated with each harvesting system. The three sites were similar in all respects and were harvested under similar soil moisture conditions. The two sites logged with skidders consisted of sandy loam surface horizons overlaying a clay layer. Soils were near saturation during logging. The helicopter deck was located on a slightly higher topographic position and the soil contained more sand.

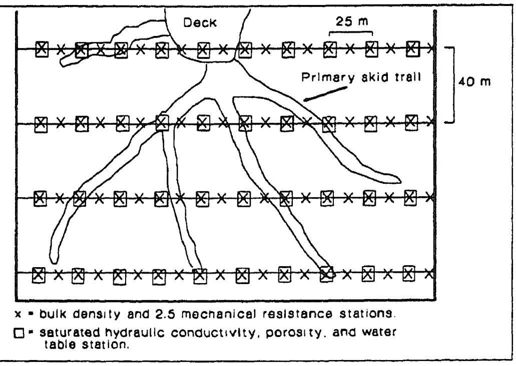
The salvage operation guidelines allowed no live trees to be removed; only broken or fallen stems were harvested. After the salvage harvests, the remaining stands were similar to a diameter limit cut, only smaller stems remained.

Field sampling of the two skidder-harvested sites consisted of installation of transect lines 40 m apart across the timber sale area. Along each transect line, mechanical resistance was measured at 5 m intervals. Mechanical resistance at each point was recorded at 2.5 cm intervals to a soil depth of 15 cm. Bulk density core samples were taken every 12.5 m along the transect. Every other bulk density core was capped and retained for total porosity, microporosity, macroporosity, and saturated hydraulic conductivity analyses. Auger holes were also established at every other bulk density station (25 m spacing) to determine the depth of the soil water table. All stations were sampled immediately before and immediately after harvest. Sampling of the helicopter deck followed the same basic design except that transect lines were spaced 20 m apart and an adjacent undisturbed area was sampled to represent the preharvest condition.

Simple t-tests were used to compare pre- and post-harvest values for l parameters within each site/harvest system. Means were determined to e significantly different at the 0.05 significance level. General sampling layout and analyses are presented in Table 1 and in Figure 1.

Table 1. Sampling and analyses procedures.

Parameter	Method	Spacing	Soil depth	Reference
		-- m --	--- cm ---	
oil bulk density	core	12.5 x 40	0-5	Blake and Hartge 1986
oil mechanical resistance	cone	5 x 40	0-15 in 2.5-cm intervals	ASAE 1986; Bradford 1986
oil porosity	desorption	25 x 40	0-5	Danielson and Sutherland 1986
aturated hydraulic conductivity	constant head	25 x 40	0-5	Klute and Dirksen 1986
ater level	auger hole	25 x 40	Na	Aust 1989



ure 1. Generic sampling design.

Results

Post-harvest soil bulk densities were higher than preharvest levels (Fig. 2); however, the two skidder-harvested areas had relatively low bulk density values before and after harvest. The helicopter deck had the highest bulk density values, 1.07 g/cm³ for preharvest and 1.46 g/cm³ for post harvest. Soil mechanical resistance followed a similar pattern: the two skidded areas had slightly higher mechanical resistance values ollowing harvest. The helicopter deck had the highest mechanical reistance (Fig. 3), which is not surprising considering the fact that the eck was intensely trafficked by tractor-trailers and front-end loaders.

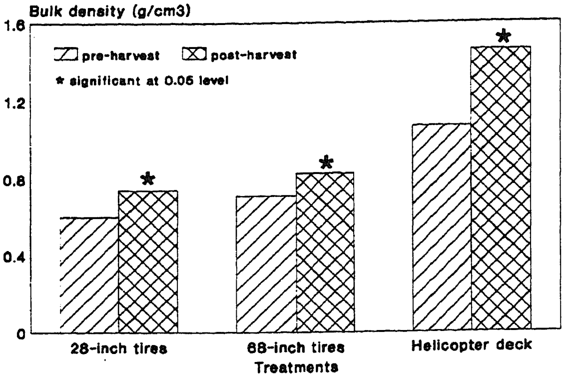


Figure 2. Soil bulk density by treatment.

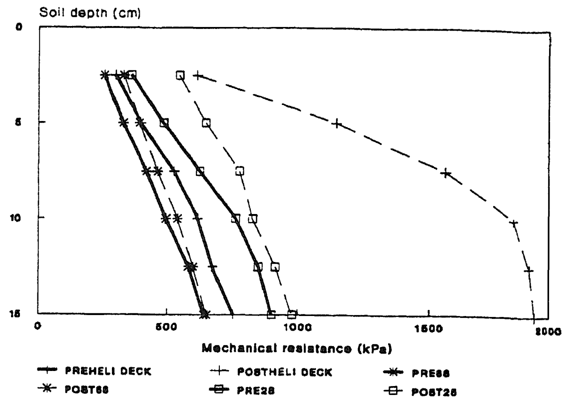


Figure 3. Soil mechanical resistance by treatment.

Total porosity values for the conventional skidder and high-flotation skidder were not significantly impacted by harvest (Fig. 4). However, the helicopter deck area, which had the largest increases in soil bulk density and mechanical resistance, had the largest change in total pore space, decreasing from 59.7 percent in the undisturbed area to 45.0 percent on the log deck.

Soil microporosity was not affected by any of the harvesting operations (Fig. 5); however, all three operations had a significantly negative impact on soil macroporosity (Fig. 6). Both skidders resulted in smaller changes in soil bulk density, mechanical resistance, and soil macroporosity. The narrow and wide tires resulted in preharvest macropore space of 22.7 and 20.0 percent, and post-harvest macropore space of 19.5 and 15.7 percent, respectively. The helicopter deck, which had the largest increase in soil bulk density and mechanical resistance, was accompanied by the largest reduction in soil macroporosity. Undisturbed macropore space decreased, from 27.3 to 13.1 percent following harvest.

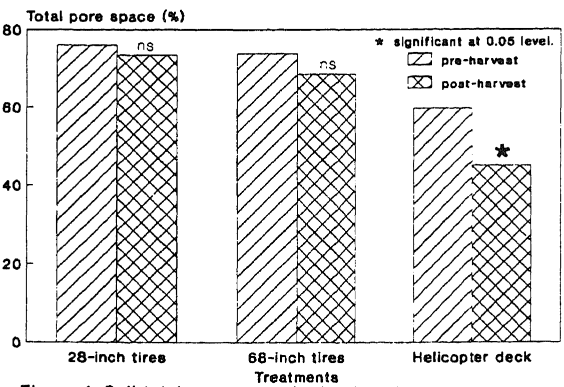


Figure 4. Soil total pore space by treatment.

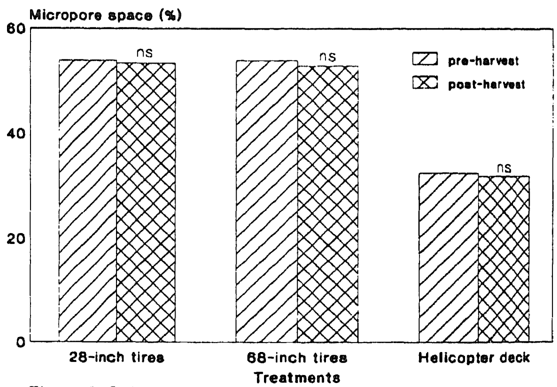


Figure 5. Soil micropore space by treatment.

Saturated hydraulic conductivity was significantly reduced by all three harvesting systems (Fig. 7). Hydraulic conductivity is affected by soil

acropore space; therefore, hydraulic conductivity decreased proportion-tely. Pre- and post-harvest saturated hydraulic conductivity values were 5.2 and 15.4 cm/hr for the 71-cm-wide tired skidder tract, 50.8 and 19.2 n/hr for the 173-cm-wide tired skidder tract, and 37.5 and 2.49 cm/hr for ne helicopter deck, respectively.

Water table levels were higher following harvest on the conventionally-kidded site (Fig. 8). On this tract the water table was 19.3 cm closer to ne soil surface following harvest.

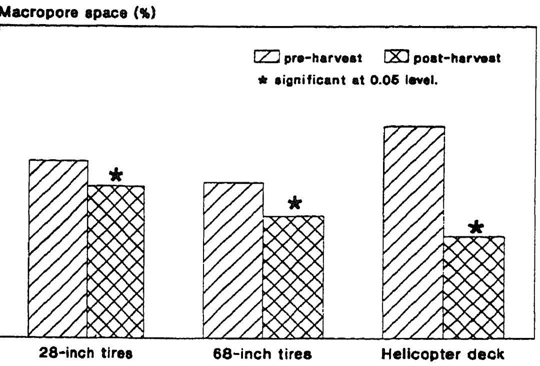


Figure 6. Soil macropore space by treatment.

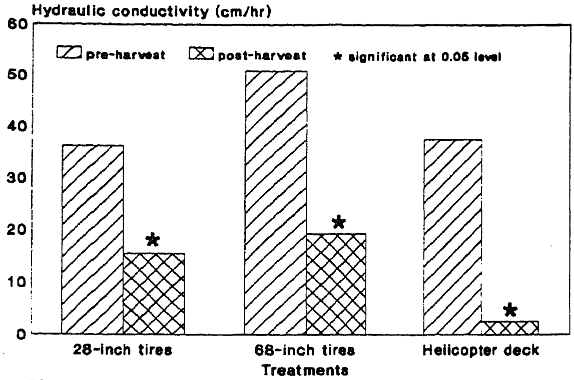


Figure 7. Saturated hydraulic conductivity by treatment.

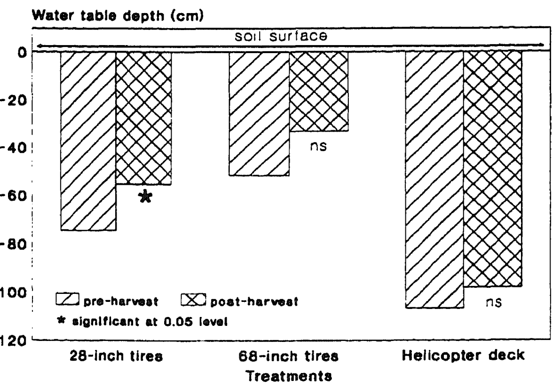


Figure 8. Soil water table depth by treatment.

Discussion

The same general impact pattern existed for all three harvest methods. Traffic during moist soil conditions compacted the soil and increased soil bulk density. Although all three treatments had significantly higher soil bulk density following harvest, only the helicopter deck area appeared to be adversely affected. The mechanical resistance data suggested the same thing. A land manager need not be overly concerned by the slight increases in soil bulk density and echanical resistance found on the two skidder harvested areas. However, acroporosity changes were significant and obvious. Although total porosty was not significantly changed, the ratio of micropores to macropores as increased. The decreases in macroporosity were the underlying causes f the decreases in saturated hydraulic conductivity. The large decreases n macroporosity were accompanied by even larger decreases in saturated hyraulic conductivity. This is best explained by the fact that water flow ecreases with the fourth power of the pore radius.

Overall, the decrease in saturated hydraulic conductivity means that hese wet, poorly aerated sites are now wetter and less aerated than before

harvesting. Several studies have indicated that such an alteration is of long duration and site productivity will be negatively affected (Greacen and Sands 1980; Wimme 1987; Aust 1989). The water table levels are also higher after harvest than previously. It is important to note that the salvage operation did not remove any live, transpiring trees. The increased water table level on the two skidded sites was not due to rainfall or decreased transpirational rates. The higher levels may be due to the reduction of water movement through the soil due to slower internal drainage.

Several conclusions can be drawn from these separate case studies. Helicopter logging is viewed as an environmentally benign harvest method (Jackson and Morris 1986), but it should be noted that the helicopter deck is an area of intense activity and trafficking. The decks often serve a much larger harvest area than a traditional skidder deck. Ameliorative practices should be considered for the helicopter decks. Secondly, high-flotation, wide-tired skidders are commonly viewed as a means of minimizing site impacts. This is true if the wide-tired skidder is used as a method of minimizing impact as opposed to increasing mobility. In the second situation, the wide tires permit continued production, but the resulting site impacts may be severe. This is somewhat analogous to the four-wheel drive mentality that allows a driver to go further down the road to get stuck. Lastly, and perhaps most importantly, the three case studies point out the continued need for preharvest planning. The salvage effort on the Francis Marion National Forest was an admirable effort, but it was an unusual situation. Better timing and implementation of harvesting is usually feasible, and every effort should be made to reduce trafficking on these wet, flat sites except during periods of drier soil conditions. Increased usage of existing soil maps can facilitate better preharvest planning.

Acknowledgments

Research was partially funded by the USDA Forest Service, Southern Forest Experiment Station, Timber Harvesting Unit, Auburn, Alabama.

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A SCANDINAVIAN CUT-TO-LENGTH HARVESTING SYSTEM FOR THINNING SOUTHERN PINE [1]

Robert A. Tufts and Richard W. Brinker [2]

Abstract. Scandinavian cut-to-length timber harvesting systems consist of two machines, a harvester and a forwarder. The harvester was designed to fell, delimb, cut the stem to-length based on specifications programmed into the machine's microprocessor, and place the pieces of the tree in a pile. The forwarder follows the harvester and picks up the pieces from the pile, loads them into a rack on the back of the machine, forwards them to roadside, and off-loads the pieces onto a trailer. As an example of this system, the Norcar™ 600 H harvester and 490 forwarder were evaluated.

Machine Description

The Norcar™ 600 H and 490 ma-
nes are based on a common eight-
eel, hydrostatically driven,
iculated-frame carrier. The flip
a switch selects four- or eight-
eel drive with or without a dif-
ential lock. The carrier has a
4 ft turning radius and 23.4
hes of ground clearance. It
sures about 7.5 ft wide (8 ft
h tracks).

Enclosed, insulated cabs provide
erous visibility, the comfort of
ting and air conditioning, and
quiet enough to enjoy the AM-FM
ereo radio that is also included.
sured noise levels during oper-
on were 71 decibels for the har-
ster and 77 decibles for the
warder (75 in a pickup truck).
erators sit in an air suspended,
veling "captain's" chair. All functions are controlled from two "monkeys' heads" at the end of the arm rests. Controls are electric over hydraulic for increased operator comfort. Also, by placing the hydraulic lines and valves outside the cab, the amount of heat in the cab is reduced.

The 21,780-lb 600 H is powered by a 102 hp Perkins™ diesel engine. It is equipped with a pedestal-mounted, HN125 crane which can telescope to a 33-ft reach and carries a Norcar H60 bar/chain harvester head. Trees up to 20.4 inches in diameter are directionally felled by the chainsaw; the tree is positioned for processing while it falls. With the tree parallel to the ground, four steel feed rollers pull it past the three self-contained delimbing knives and buck it to length with the felling saw.

The harvester is equipped with a stem measuring device developed by Kajaanin Automatiikka Oy of Finland. Sensors read diameter and length as a stem feeds through the processing head and relay the data to a computer, which can be programmed for up to ten lengths with diameter limits. The operator simply fells the tree and pushes the button for the

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Paper presented at Sixth Biennial
thern Silvicultural Research Con-
ence, Memphis, TN, Oct. 30-Nov.
1990.

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desired product; the computer controls the length of stem fed through the head and checks for the diameter limit. For example, the operator pushes the button for a 16-ft sawlog with a minimum diameter limit of 6 inches. Accordingly, 16 ft of the stem feeds through the head unless the 6-inch limit is reached first. If the latter occurs, feeding stops, operator selects the button for the appropriate length, and the computer makes the adjustment.

Powered by an 80-hp Perkins diesel engine, the 16,500-lb 490 forwarder has a rated carrying capacity equal to its weight. It is equipped with an RKP loader with a telescopic reach of 24.6 ft.

Advantages And Disadvantages

Based on my observations, the Norcar harvesting system has several advantages over conventional timber harvesting systems. The greatest advantage is the minimal residual stand damage. With a 33-ft reach, the 600TH can harvest a 60-ft-wide swath with one pass leaving only two tire tracks. The eight-wheel carrier produces minimal ground bearing pressure. And, the 600TH operator can process the stems in front of the machine, stacking the merchantable pieces to the side and dropping the limbs and top in front of the machine before driving forward, further reducing soil disturbance. Since the machine is only 7.5 ft wide it can operate in a purely selective mode rather than remove a row for access. The unique cutting method reduces damage to residual trees. Rather than force the tree to the ground as a feller buncher would, after severing the tree from the stump, the butt is pulled toward the machine allowing the top to fall in the growing space it occupied rather than through the surrounding stand.

The forwarder follows in the track of the harvester to load the merchantable stems, so less than 13 percent of the area experiences any traffic. Since the forwarder carries six times the load of a skidder, the total number of passes is reduced. Because stems are cut-to-length prior to forwarding, there are no long stems that might damage residual trees, and the pieces are carried rather than dragged along the ground. Since the forwarder off-loads the wood to a trailer there is no need for a large landing; in fact, the trailer can be parked along the side of a road without any landing. Also, by processing the trees in the woods, there is no large pile of limbs and tops near each landing as in conventional harvesting operations.

The ability to merchandize each tree in the woods and separate products allows the system to maximize the profit potential of the stand. The separation of products also reduces the transportation cost. Only sawlog material is hauled to the sawmill rather than hauling the entire merchantable stem to the sawmill where pulpwood is separated and transported to another facility. The cut-to-length products produce a neater truck load and eliminate the need to have stems extending beyond the back of a trailer.

Because of the high fixed cost associated with the system, reduced productivity caused by quotas present a financial hazard to independent contractors who consider this system. Also, the complexity of the machine in

terms of electric over hydraulic controls will require a mechanic with more skill than those normally employed by timber harvesting contractors. Because these machines are manufactured in Finland, there is a potential problem for support of the machine and operator training.

Norcar 600 H Harvester

The total time to select, cut, and process is shown in Figure 1. The average time was 26.2 sec., or 2.3 trees/min. The time to select, cut, and process ranged from 10.8-53.8 sec. The portion for the operator to select the tree to harvest, position the head, and cut the tree averaged 10.8 sec. while processing the tree once the tree had been cut averaged 15.3 sec.

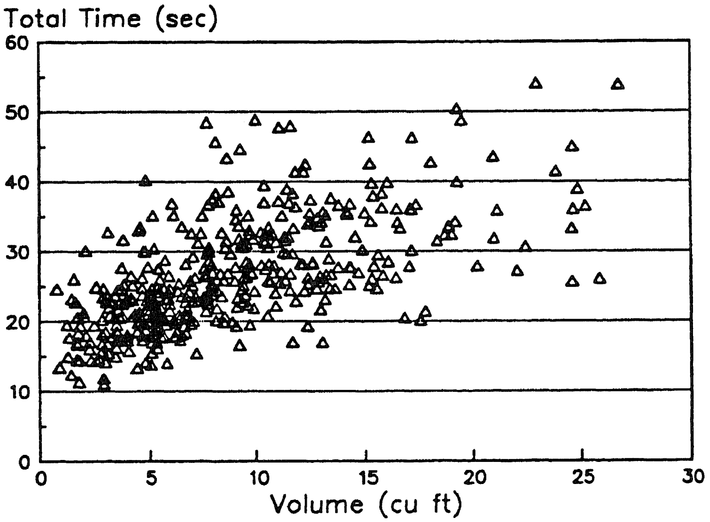


Figure 1. Select, cut, and process times for 435 observations for the Norcar 600 H harvester.

Figure 1 indicates that there was a relationship between select, cut and process time, and tree size. Tree size averaged 8.76 ft^3 and ranged from 0.78-26.74 ft^3 (3.6-14.0 inches dbh, with an average of 7.7 inches). The time to process the tree was a function of the number of pieces processed and the merchantable volume. The time to select and cut the tree had a low, significant correlation with tree size.

Productivity was calculated (in cords; Fig. 2) on a productive machine hour basis (PMH), with no allowance for mechanical or nonmechanical interruptions. A productivity was calculated for each tree based on the tree's merchantable volume and the time to select, cut, and process the tree. An average of 7.1 sec. for move between cutting locations was added to the select, cut, and process time to calculate the total time per tree. Productivity ranged from 0.9-23.8 cords/PMH, with an average of 9.2 cords/PMH.

The best model to predict the productivity in cords per PMH for a Norcar 600 H harvester was:

$$= -1.539 + 0.6683 * \text{dbh} + 0.9754 * \text{Volume} \\ -0.1257 * \text{Volume} * \text{Pieces}.$$

The coefficient of determination for the model was 0.873.

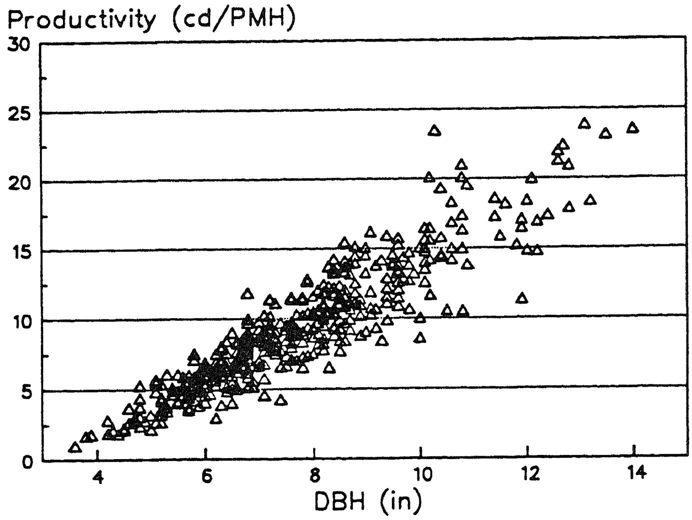


Figure 2. Calculated productivity for the 435 observations for the Norcar 600 H harvester.

The dbh was the m significant predictor productivity, explain 84 percent of the var bility in the data (was also very highly c related with merchanta volume). As tree s increased, the vol component of productiv increased faster than total time component; productivity increa with tree size. Howev productivity decreased 0.13 cords/PMH for e additional piece proc sed. The range of d used to develop this del precludes its use trees larger than 14 ches in dbh.

An hourly cost calculated for the h vester by dividing the minimum annual equivalent cost (Tufts 1985) dur the first 4 years of operation by the productive machine hours. Payme were based on a purchase price of $300,000 with 90 percent financed at percent for 5 years. A 28 percent marginal tax rate was used to calcul the impact of federal income taxes. The alternative rate of return wa percent. The sum-of-the-years-digits depreciation method for an 8-y life and a 20 percent residual value was used to estimate the salvage va at the end of each year.

Variable costs included fuel and lubrication, maintenance and repa insurance, and labor. Fuel and lubrication costs were estimated at $2. PMH, and repair and maintenance costs were estimated at $40/PMH. Haz insurance was calculated at 4 percent of the beginning-of-the-year value the machine. A labor rate of $10 per scheduled machine hour, plus times the base rate for overtime, plus an extra 30 percent for fringe be fits was used to calculate annual labor expenses. Fuel and lubricat costs were assumed to escalate at 10 percent per year; maintenance and pair at 15 percent; and labor at 5 percent. Operating 235 9-hour days with a utilization of 55 percent would produce 1163.25 PMH.

Before-tax cash flows were split between operating expenses ($90,9 which increased yearly, and machine payments ($73,720). Federal income savings result from decreasing taxable income by the amount of deprec tion, operating expenses, and interest on the loan. The minimum ann equivalent cost (AEC) is based on an ownership period of 4 years and equal to $123,413 per year. The cost per PMH was $123,413/1163.25 PMH, $106.09/PMH. Predicted productivity and cost per cord for a typical st are depicted in Figure 3.

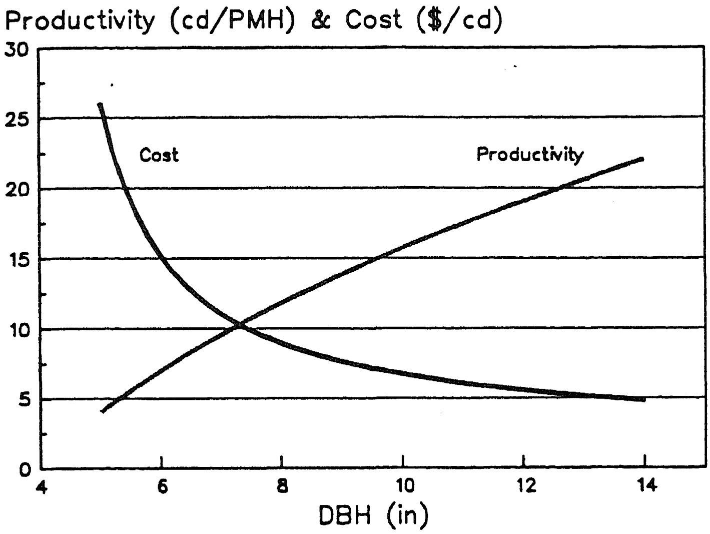


Figure 3. Predicted productivity and cost per cord for the Norcar 600 H harvester thinning a pine plantation.

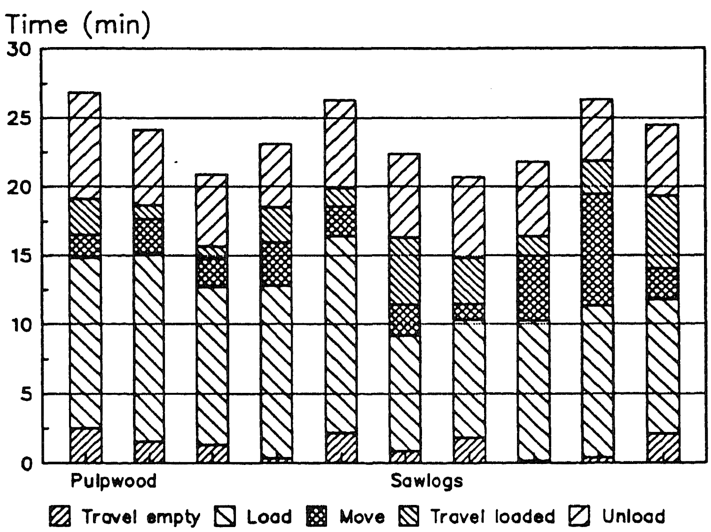


Figure 4. Distribution of time among the five elements for five loads of pulpwood and five loads of sawlogs for the Norcar 490 cycle.

Norcar 490 Forwarder

The forwarder cycle was divided into five elements, and data were collected on each element. Figure 4 shows the distribution of total time for ten forwarder cycles. Pulpwood was the product produced for the first five of the loads and the other five were small sawlogs. The time is divided into travel with no load, loading product, moving during loading, travel with a load, and unloading. For the five loads of pulpwood, 76.9 percent of the time the operator was either loading or unloading the machine. Traveling to and from the woods consumed 13.6 percent of the time and the remaining 9.5 percent was spent moving during loading. The average load weighed 16,310 lb and required 24.28 min. for a complete cycle. The average productivity for the forwarder while producing pulpwood was 7.58 cords/PMH.

For five loads of small sawlogs the operator was loading or unloading the machine 63.8 percent of the time, moving during loading 14.5 percent of the time, and traveling 21.7 percent of the time. An average load weighed 18,180 lb, requiring 23.15 min. for a complete cycle. Average productivity was 8.87 cords/PMH.

The average load of pulpwood contained 85 pieces compared with only 42 for a load of small sawlogs. The greatest time difference was for loading where pulpwood required 12.8 min. compared with 9.3 min. for sawlogs. Unloading times were almost equal, with 5.9 min. for pulpwood and 5.4 min. for sawlogs. The average time per load was 23.6 min., but the average load size for sawlogs was 1870 lb, or 0.35 cords larger than the average load of pulpwood.

Predicted travel speed for the forwarder was 2.31 mph empty and 1.85 mph loaded. The time to place a grapple load on the machine was a function of the number of pieces in the grapple and whether additional handling was necessary to align the ends of the pieces. The time to move between loading locations was a function of the distance moved, and unloading time was a function of the number of grapple swings to unload, the number of pieces on the load, and the type of product.

An hourly cost was calculated for the forwarder using the same methodology and assumptions as for the harvester except that the purchase price was $150,000, fuel and lubrication costs were $2/PMH, and repair and maintenance costs were $20/PMH. The forwarder utilization was 65 percent, or 1374.75 PMH/year.

Before-tax cash flows were split between operating expenses, $65,267, which increased yearly, and machine payments, $36,860. The minimum AEC was based on an ownership period of 4 years and was equal to $65,059/yr. The cost per PMH was $65,059/1374.75 PMH, or $47.32/PMH.

The forwarding cost/cord for pulpwood, based on the average productivity and estimated cost would be $6.24 ($47.32 per PMH/7.58 cords/PMH). The forwarding cost for small sawlogs would be $5.33/cord. These costs would vary with forwarding distance, pile size, and the distance between piles.

Conclusion

The Norcar harvesting system was very productive while performing second thinnings in loblolly pine plantations. Costs were competitive, if not lower than, conventional harvesting systems, and residual stand damage appeared less than that caused by other harvesting systems. Tree size had a significant impact on productivity, and the high fixed cost of the system requires a high level of productivity.

Literature Cited

Tufts, R.A. 1985. Equipment replacement analysis. The Compiler 3(2):16-17.

MANAGING LONGLEAF PINE UNDER THE SELECTION SYSTEM--PROMISES AND PROBLEMS [1]

Robert M. Farrar, Jr., and William D. Boyer [2]

Abstract. Six- and ten-year results are reported on group-selection management of two small tracts of longleaf pine (Pinus palustris) in south Alabama. One stand is managed via volume control in the sawtimber component, the other is managed via a structure target, and both are prescription burned on a 3-year cycle. Information is given on structure changes, volume production, and reproduction establishment and development. Comparisons are made with an adjacent tract managed and prescription burned for decades under an even-aged shelterwood system. Advantages and disadvantages of the group-selection system for longleaf pine, both observed and anticipated, are discussed.

Introduction

Longleaf pine (Pinus palustris) generally regarded as a species st managed in natural stands using en-aged silvicultural systems and specifically well suited to a elterwood system (Croker and Boyer 75). Due principally to seedling tolerance to competition, it is t ordinarily thought of as being ited to an uneven-aged or selecon system. However, we have evince that the species can be maned under a group-selection system at includes cyclic prescribed rning for seedbed preparation and ntrol of unwanted vegetation. The llowing paper briefly describes e first 6- and 10-year results from two stands managed under such a system.

Methods

Study Areas

Two tracts of natural longleaf pine forest, 30 and 36 ac in size, were surveyed and established as selection management demonstrations on the Escambia Experimental Forest (EEF) in southern Alabama (Table 1). One area, designated the "volume/guiding-dbh-limit" (V/GDL) stand, was inventoried and first cut during 1977-78. The other area, designated the "basal area-maximum dbh-q" (BDq) stand, was inventoried and first cut during 1981-83. Both were chosen because they contained irregular, patchy areas of mature longleaf pine and some groups and patches of seedlings and saplings. Neither had received significant cutting during the decade before selection as demonstrations, but both had been periodically burned for decades, treated once for hardwood control (Table 1), and were relatively free of woody competition.

Paper presented at Sixth Biennial uthern Silvicultural Research Conrence, Memphis, TN, Oct. 30-Nov. 1990.

Principal Silviculturists, South-n Forest Exp. Sta., located, rectively, Mississippi State Univ., d Auburn Univ., AL.

Table 1. Stand data for longleaf pine demonstration stands.

Item/operation	V/GDL stand	BDq stand	Farm 40
Location	EEF Cpts. 147-148	EEF Cpt. 65	EEF Cpt. 15
Area	36 ac	30 ac	40 ac
TSI	1980	1965-66	1948-49-50
Prescribed burns	1948	1951	1954
	1954	1953	1957
	1957	1961	1963
	1963	1963	1968
	1968	1965	1973
	1971	1968	1974
	1974	1972	1976
	1976	1976	1978
	1979	1978	1981
	1982	1981	1985
	1985	1984	1988
	1988	1987	1989

Regulation

The V/GDL stand is regulated under the system developed by Reyno (1959, 1969) and Reynolds and others (1984) for uneven-aged loblolly-sho leaf pine (*P. taeda* and *P. echinata*) stands in southern Arkansas. Sim stated, the stand is regulated under volume control in the sawtimber c ponent using a guiding dbh limit to help allocate the allowable cut. desired volume in the sawtimber component at the end of a cutting cycle adopted as a target, the sawtimber volume growth rate is estimated, a c ting cycle (dependent on the sawtimber growth rate) is adopted, and a s timber volume is left after cutting (A-C) that will grow at the determi rate to give the desired standing volume at the end of the cutting cyc The GDL is the dbh class in the upper portion of the stand table in above which all the cut could be taken, if desired. However, if this w done, a diameter-limit cut would result and some good, fast-growing tr above the limit might be prematurely cut while some poor, slow-grow trees below the limit might be left. Hence, the term "guiding-dbh-lim is a guide, and in fact, good trees above the limit are left and poor tr below the limit are cut to result in the allowable cut.

Specifically, the V/GDL prescription was to leave a volume of ab 4,000 FBM Doyle rule, or 6,500 FBM International 1/4-inch rule (Int.1 which, with an assumed growth rate of 200 FBM Doyle (300 FBM Int.1/ would grow in 5 years to obtain about 5,000 FBM Doyle or 8,000 FBM Int.1

The Bdq stand is managed under structure control in which the ent merchantable stand table is treated -- not just the sawtimber. Thus, m agement is more complete and, as we shall see, more objective. Sim

:ated, an A-C target structure (stand table) specified by stand basal :ea, maximum dbh of trees to be left, and a 1-inch q (the fixed ratio of ıe numbers of trees in succeeding 1-inch dbh classes) is adopted. Then ıe before-cut (B-C) inventory stand table is compared with the A-C target ıd surplus trees in excess of the target stand table are then harvested. : there are deficits between the A-C target and the B-C inventory, then ıough basal area in trees above the target is left to ensure that the pre- :ribed A-C basal area remains. [See Farrar (1981, 1984) and Farrar et al. .989) for more information and other references on both V/GDL and Bdq ·gulation.]

The BDq prescription was to leave 50 ft² of merchantable basal area (in :ees over 3.5 inches dbh), assume a residual maximum dbh of 20 inches, and se a 1-inch q of 1.2.

ıventories

The merchantable pine stand in each area is given periodic 100-percent ıventories by 1-inch dbh classes. These inventories include those to de- ·rmine the B-C stand table, to mark the trees to be cut, and to tally any ɔgging or other damage for salvage. At the time of each B-C inventory, a :etch map is made of the stand to show any features such as roads or :reams and any concentrations or scarcities of timber sizes (e.g., saw- imber, pulpwood). Volumes are determined by use of local volume functions ıd custom inventory summary software for the EEF (Farrar 1986). At the ime of the B-C volume inventory, pine reproduction is also sampled and)0 nested temporary sample plots are systematically inventoried on each :act. The nested plot consists of a central circular milacre, on which ·edlings (over 0.5 to 4.5 ft in height) are tallied, within a circular /100-ac plot, on which saplings (1-, 2-, and 3-inch dbh classes) are allied.

arking

The marking rules to obtain the allowable cut for both V/GDL and BDq ·thods are basically simple. The poorer trees with respect to vigor, stem ɔrm, and spatial position are removed in the allowable cut, and the better :ees are left, while also adhering to the following group-selection rules: l) Enlarge any existing group of reproduction by cutting merchantable bor- ·r trees that are candidates for removal but only if reproduction exists eneath these trees; (2) Start a new group of reproduction by removing ıose trees in and above the GDL or maximum dbh class that need to be cut ıd have reproduction beneath them; and (3) Remove the rest of the allow- ɔle cut in trees taken singly in thinnings in the closed remainder of the tand. The main logistical problem is to mark all of the allowable cut in ıe pass through the stand. This can be practically achieved by dividing ıe stand into, say, quarters; allocating about one-quarter of the cut to ach quarter; trying to hit the cut quotas in each quarter; and adjusting he cut up or down as required from quarter to quarter to mark the allow- ɔle cut. [See Marquis (1978) for more details on this operation.]

Note that there is no attempt to allocate any certain area to any tree ize class and we do not keep records on the area occupied by any size age) class. The application of the group-selection marking rules is

depended upon to eventually create the desired uneven-aged structure. T this will probably occur is intuitively seen in the BDq system but is so apparent in the V/GDL system.

Since growth on these medium sites was less than anticipated, cutt cycles were lengthened to 10 years to provide an adequate operable c Thus, the V/GDL stand was cut initially in 1977 and not again until 19 and the BDq stand was cut only initially in 1982-83 and not in 1987.

Treatments

Both stands have received treatment to reduce unwanted woody vegetat that cannot be effectively controlled by prescribed fire. All undesira stems 1-inch dbh and larger were injected with herbicide. The V/GDL st was treated in 1980 (Tordon 101-R) and the BDq stand in 1965-66 (2, amine).

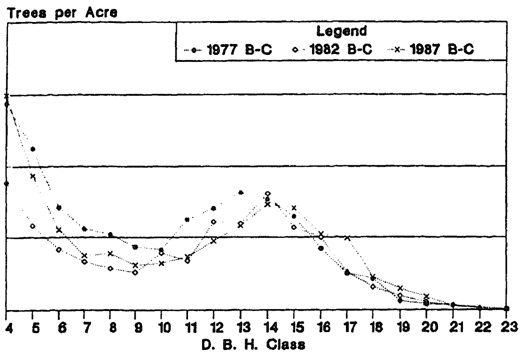
Once the unwanted woody vegetation is brought under control, as abo continued control is by periodic prescribed fire. Both stands are win burned on a 3-year cycle. Occasionally, 2-year spring burns may be impo for a few cycles if the 3-year winter burns do not effectively keep ha woods small. Because burns are prescribed to give complete coverage of demonstration areas, they are not necessarily best for all timber siz Burns are most effective in the groups of closed timber, from large sapl to mature sawtimber in size, and are somewhat less effective in the gro of reproduction where fuels are principally grasses rather than pine ne les. They also kill varying amounts of fire-susceptible reproduction neath parent trees but since regeneration is cyclically re-established these fires also prepare seedbeds, the net effect so far, as we will s is that regeneration is regularly established and much of it retained.

Results And Discussion

Structure

The structure of the V/GDL merchantable stand has not yet assumed classic reverse-J dbh distribution generally associated with balanced even-aged stands (Fig. 1) because: (1) the stand has been under select management for only 10 years; (2) it had one initial cut that was ess tially an improvement cut/low thinning; and (3), more importantly, there nothing inherent in the V/GDL regulation method to ensure a reverse-J d tribution. However, it may eventually result in such a distribution not as soon as BDq. Some loblolly-shortleaf pine stands managed for d ades in south Arkansas under this system did not necessarily create verse-J dbh distributions in the process (Murphy and Farrar 1981). It mains to be seen if the V/GDL group-selection system employed here will, its own, result in a classic reverse-J distribution or if this condition indeed necessary for successful uneven-aged management in longleaf pine.

The structure of the BDq merchantable stand is approaching a revers dbh distribution because the cutting specifically tailors the stand tow such a distribution. Note in Figure 2 that above the 10-inch dbh cla the structure assumes a reverse-J distribution more or less parallel to



igure 1. Frequency by merchantable -inch dbh classes—V/GDL stand.

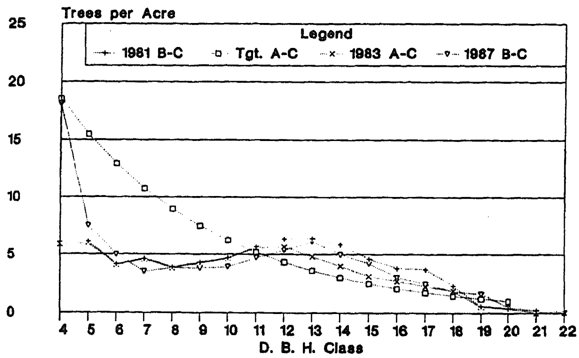


Figure 2. Frequency by merchantable 1-inch dbh classes— BDq stand.

-C target distribution for this reason and that there has been considerble ingrowth into the smaller dbh classes; particularly into the 4-inch lass. As management and recruitment from reproduction continues, the tand should more completely approach such a distribution.

rowth

The merchantable stand periodic growth for 10 years is shown for the /GDL stand in Table 2 and for 6 years for the BDq stand in Table 3. rowth has not been outstanding in either case, amounting to about 30 ft^3 ac/yr, or about 140 FBM/ac/yr Doyle, which is considerably less than the 00 expected. At this rate, a 5-year cutting cycle results in about 700 3M Doyle available for cut which is not economically operable, assuming ,000 FBM Doyle to be operable. With this sawtimber growth rate, a 10-year itting cycle results in growth of about 1,400 FBM Doyle growth, which is conomical to cut.

The poor growth during the first growth period in each stand resulted rom volume loss caused by mortality. In the V/GDL stand the actual causes f the unsalvaged mortality are unknown, but they were most likely lighting strikes and associated bark beetle attacks; possibly some was from ogging damage. In the BDq stand the negative volume change is thought to e for the same reasons plus mortality from a 1983 windstorm. Although the atter was largely salvaged and captured in the cut, it did cause the cut o be about 300 FBM Doyle/ac above the amount marked and reduced the base or growth. During the second period in the V/GDL stand, the relatively arge positive change in volume suggests minor mortality and a growth rate nat we think is more normal for such stands.

ib-merchantable Stand

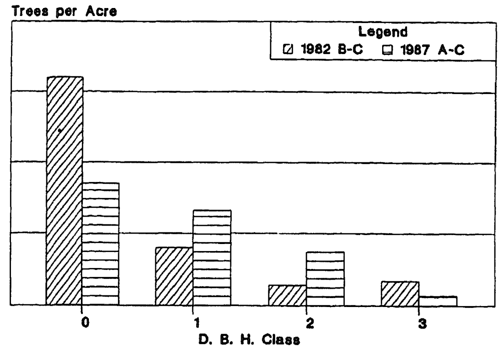
Regeneration appears to be adequate and sustainable in both the V/GDL nd BDq stands (Fig. 3 and 4). In each case, during the management period, ne numbers of trees in each sapling dbh class has increased. If the numer of seedling and sapling trees dictated by the adopted A-C target BDq tructure is taken as an absolute minimum, then the reproduction amount apears to be more than adequate (Fig. 4). In both cases, a decrease in eedlings during the management period occurred. However, the seedling

Table 2. Ten-year production history— V/GDL selection stand.

	Merchantable stand/ Trees	Basal area	Volume	Sawtimber stand/ Volume	Doyle	Int.1/4"
	(no./ac)	(ft^2/ac)	(ft^3/ac)	(ft^3/ac)	- (bd ft/ac) -	
B-C inventory 1977	98	62.0	1,576	1,274	4,808	7,988
B-C inventory 1982	72	53.7	1,394	1,177	4,532	7,414
Change 1977-82	-26	-8.3	-182	-97	-276	-574
Cut 1977-78	30	12.3	288	205	846	1,319
Growth 1977-82	4	4.0	106	108	570	745
PAI 1977-82	1	0.8	21	22	114	149
B-C inventory 1982	72	53.7	1,394	1,177	4,532	7,414
B-C inventory 1987	88	62.4	1,613	1,357	5,437	8,637
Change 1982-87	16	8.7	219	180	905	1,223
Cut 1982-83	0	0	0	0	0	0
Growth 1982-87	16	8.7	219	180	905	1,223
PAI 1982-87	3	1.7	44	36	181	245
Cut 1987	13	11.2	297	261	1,126	1,694
A-C inventory 1987	75	51.2	1,316	1,096	4,311	6,943

Table 3. Six-year production history— BDq selection stand.

	Merchantable stand/ Trees	Basal area	Volume	Sawtimber stand/ Volume	Doyle	Int.1/4"
	(no./ac)	(ft^2/ac)	(ft^3/ac)	(ft^3/ac)	- (bd ft/ac) -	
B-C inventory 1981	74	54.3	1,404	1,154	4,404	7,254
B-C inventory 1987	81	49.2	1,244	1,012	3,893	6,375
Change 1981-87	7	-5.1	-160	-142	-511	-879
Cut 1982-83	10	11.9	323	293	1,222	1,888
Growth 1981-87	17	6.8	163	151	711	1,009
PAI 1981-87	3	1.1	27	25	119	168
Cut 1987-88	0	0	0	0	0	0
A-C inventory 1987	81	49.2	1,244	1,012	3,893	6,375



'igure 3. Seedling and sapling 1-inch dbh class frequencies—V/GDL stand.

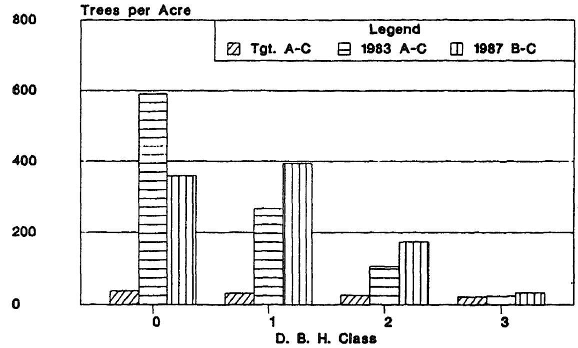
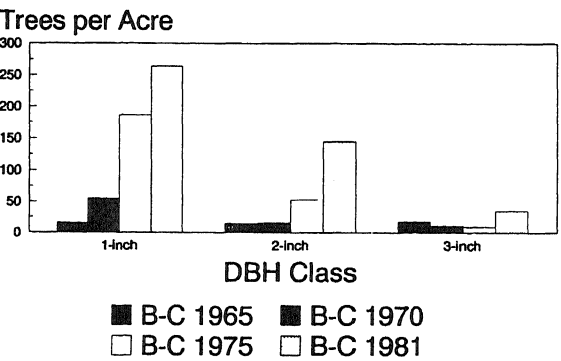


Figure 4. Seedling and sapling 1-inch dbh class frequencies—BDq stand.

umbers are likely to fluctuate due to repeated burning, intermittent seed rops, logging damage, and recruitment into the sapling classes. In both ases, for these periods there was no logging so the change is attributable ostly to burning and recruitment. We might add that for a 10-year period rior to BDq management of the stand, its irregular stand of mature natural ongleaf had similar basal area density, sustained periodic light cutting, nd received burns on a 3-year cycle as was the subsequent case. During his period, sapling frequencies also increased in this stand with time Fig. 5). This observation suggested that longleaf could be managed and eproduced under a selection system that included the cyclic prescribed urning required for seedbed preparation and control of hardwood ompetition.



'igure 5. Sapling 1-inch dbh class frequencies— EEF compartment 65.

Observations

Thus far we have found no serious problem to suggest that natural stands of longleaf pine on longleaf pine/bluestem (Andropogon spp.) sites on the rolling lower Gulf Coastal Plain cannot be managed and sustained under a group-selection system. This system, for longleaf pine, requires regular burning for the multiple purposes of seedbed preparation, unwanted vegetation control, and hazard reduction. However, successful management for 10 years or less does not prove a system. Proof will require practice and monitoring for several more decades.

Further, the growth of such stands is not likely to reach the optimum hat may be achieved under an even-aged shelterwood system using large locks (> 40 ac) in each age class. The difference is probably due to the ompetition exerted by large timber on adjacent smaller trees, particularly

seedlings and saplings. The competitive effect of large timber root systems extends for about the height of the large timber (or about 1 chain) into adjacent seedling and sapling stands or groups and retards their development, with the effect decreasing with distance. Thus, a circular opening of about 1/3 ac is entirely under competition from adjacent large timber. The effect is reduced at an exponentially decreasing rate as opening size increases. For example, a 5-ac circular opening has about 2.8 ac, or 56 percent of its central area free of competition from adjacent mature timber; while a 40-ac opening would have about 31 ac, or 83 percent of its central area similarly free.

How much more efficient in wood production such a system of large even-aged stands will be is unknown, but it appears that a forest of small even-aged stands (about 5 ac each) grows no better than our group-selection stands so far (Table 4). In Table 4 the periodic growth for the past 10 years is shown for our longleaf pine Farm 40 demonstration (Table 1) on the EEF. It has been managed for more than 40 years under an even-aged system of shelterwood in small blocks of fractions of an acre to a few acres in size and with periodic prescribed burning. This stand is managed toward area regulation with an 80-year rotation and a 10-year cutting interval. It is growing at rates comparable to those of our V/GDL and BDq stands. A set of fully-regulated even-aged stands under area control has not yet been achieved in the Farm 40, but their composite is beginning to reflect the classic reverse-J dbh distribution expected under regulation (Fig. 6). Thus, it appears that there will be little volume production difference between a longleaf stand managed and regulated under group-selection and a similar area managed and regulated under an even-aged system that creates a balanced set of age classes in small stands of a few acres each.

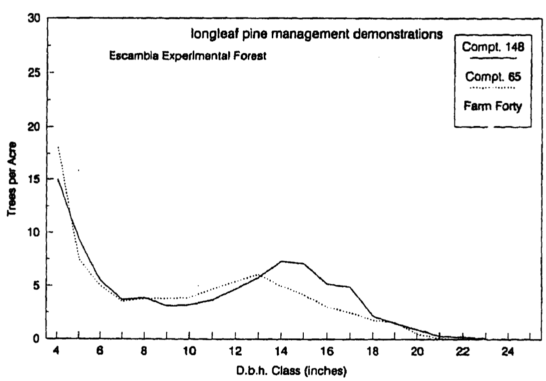


Figure 6. The 1988 merchantable 1-inch dbh class frequencies--Farm 40, V/GDL (compt. 148), and BDq (compt. 65) stands.

In addition to the necessary increase in the cutting cycle from 5 to 10 years dictated by the growth rates, further changes in the management of both selection stands are planned. In the V/GDL stand, we expect to gradually increase the residual sawtimber volume to 4,500 to 5,000 FBM Doyle (7,000 to 8,000 FBM Int. 1/4) to improve the growth base, growth, and allowable cut. For the same reason, the residual basal area in the BDq stand will gradually be increased to 55 to 60 ft^2/ac. Both are feasible targets that can be sustained as management continues and structure improves.

Good data on stem frequencies were obtained in the reproduction inventories but there was no information on the competitive or "free-to-grow"

Table 4. Ten-year production history—Farm 40 even-aged stands.

	Merchantable stand/			Sawtimber stand/		
	Trees	Basal area	Volume	Volume	Doyle	Int.1/4"
	(no./ac)	(ft^2/ac)	(ft^3/ac)	(ft^3/ac)	- (bd	ft/ac) -
B-C inventory 1977	119	50.8	1,200	857	3,376	5,437
B-C inventory 1982	96	48.0	1,170	844	3,424	5,393
Change 1977-82	-23	-2.8	-30	-13	48	-44
Cut 1977-82	33	8.2	164	90	286	542
Growth 1977-82	10	5.4	134	77	334	498
PAI 1977-82	2	1.1	27	15	67	100
B-C inventory 1982	96	48.0	1,170	844	3,424	5,393
B-C inventory 1987	119	57.8	1,401	1,002	4,106	6,417
Change 1982-87	23	9.8	231	158	682	1,024
Cut 1982-83	0	0	0	0	0	0
Growth 1982-87	23	9.8	231	158	682	1,024
PAI 1982-87	5	2.0	46	32	136	205
Cut 1988	6	5.3	141	121	460	757

status of these seedlings and saplings. In future reproduction inventories, this information will be obtained so we can better assess the portion of the reproduction likely to contribute to ingrowth into the larger sizes.

Advantages And Disadvantages

To summarize our short-term experience with the group-selection system in longleaf pine, a set of the major advantages and disadvantages encountered, with annotations, are listed below. Some are specific to longleaf pine and longleaf is mentioned in them. Others generally apply to a selection system in loblolly, longleaf, or shortleaf pine. They are not necessarily in any order of importance because this will vary with the objectives, experience, and skill level of the practitioner.

Advantages

* It provides a possible alternative to even-aged management in longleaf pine stands on medium sites where competing unwanted vegetation can be largely controlled by cyclic prescribed burning, including

growing-season burns (the comparative resistance of longleaf pine seedlings and saplings to fire damage allows regular burning of entire units, a practice generally deemed too dangerous for use with other southern pines under selection management).

* A constant high-forest cover is maintained; no large areas are ever laid bare.

* Regeneration is more or less continuous (not confined to one short, risky period as in even-aged systems).

* Full regulation is relatively easily, quickly, and automatically achieved if the selection system is properly applied to somewhat irregular stands (conversely, a full rotation is required to regulate a forest of even-aged stands).

* Small areas (e.g., about 40 ac) can be economically managed for regular, essentially even-flow, cuts within a relatively short period, depending upon the initial age/size class distributions (economic cuts from a small forest of even-aged stands may be irregular and not optimally applied until near the end of the first rotation).

* Volume yields of a small selection stand of longleaf pine (e.g., about 40 ac) will likely be as good as that from a similarly-sized small forest comprised of many small even-aged stands, due to large zones of inter-stand competition in both cases.

* The diversity of age (size) classes found within a selection stand may be more aesthetically appealing to some.

* In longleaf pine, it may provide better habitat for some rare and/or endangered species of wildlife [e.g., red-cockaded woodpecker (*Picoides borealis*), gopher tortoise (*Gopherus polyphemus*), indigo snake (*Drymarchon corais couperi*)] due possibly to concentration and maintenance of suitable varied habitat within an appropriately sized total stand area without the disruption caused by final harvest and regeneration of relatively large even-aged stands.

* Within limits, smaller (younger) or larger (older) trees can be grown under regulation with simply a change in cutting cycle and/or maximum dbh and no change in stand area [in even-aged systems such a change would require a change in rotation length, a change in the number of cutting intervals, a change in the number of stands, re-division of the fixed area (or annexation of additional area), and another rotation to achieve regulation].

Disadvantages

* Regular prescribed burning in group-selection stands of longleaf pine does not do the best job for all tree size classes and is not currently a viable option for other southern pines [burning in even-aged stands can be better tailored to individual age (size) class needs].

* Some timber stand improvement work other than burning (e.g., tree injection with herbicide or mechanical cutting in spring) may be required in longleaf pine stands about every 20 years (even-aged stands probably need to be so treated only once in a rotation, at the time of the shelterwood preparatory or seed cut).

* Volume yields in longleaf pine group-selection stands will likely be less than that from a forest of large even-aged stands (in the latter situation the zone of competition between different size classes of timber is minimized).

* Selection management requires more time and attention, with attendant costs, especially in early stages of adoption when personnel knowledge and experience are at their lowest.

* Significant stand inventory data (i.e., stand and/or stock table) are required at each cutting cycle to guide proper cutting and can be a significant added cost.

* A 10-year cutting cycle is probably the shortest practical one for most longleaf pine sites (most even-aged stands on the same sites and less than about 50 years old can probably be economically thinned at a 5-year interval).

* A selection system in longleaf pine may not be best for some wildlife species, such as bobwhite quail (Colinus virginianus), although it may be entirely suitable for others such as white-tailed deer (Odocoileus virginianus), turkey (Meleagris gallopavo sylvestris), and fox squirrel (Sciurus niger bachmani, S. n. niger).

* A selection system may not work well for longleaf pine on very poor, dry, sandy sites, wet flatwoods sites with dense palmetto (Serenoa repens) understories, or very good mesic sites because effective prescribed burning for competition control and/or seedbed preparation may be difficult to achieve.

* In this system it is difficult to economically and logistically apply area-wise mechanical or chemical control of unwanted vegetation.

* The time required to grow longleaf pines of a given size will be longer in selection than even-aged stands due to extended periods of varying partial suppression before reaching the upper canopy. Thus, it may take several decades to convert a classical even-aged stand to a regulated selection stand.

Acknowledgment

The site of this research is maintained in cooperation with the T.R. Miller Mill Co., Brewton, Alabama. Research was conducted in cooperation with the School of Forestry and the Alabama Agricultural Experiment Station, Auburn, Alabama.

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A SUBJECTIVE DECISION MODEL FOR CLASSIFICATION OF UNEVEN-AGED SILVICULTURAL SYSTEMS [1]

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Abstract. A subjective decision model for uneven-aged stands is presented by which a silviculturist can objectively assess whether a hypothetical system proposed for implementation meets the accepted criteria that constitute a theoretically robust uneven-aged system. The model is based on subjective and objective standards that define and characterize uneven-aged silviculture based on historical patterns, contemporary research, and applied understanding of the method. These standards derive directly from the underlying definitions and assumptions upon which uneven-aged silviculture is based.

Introduction

As foresters impose uneven-aged silviculture across the South, a danger exists that stands may be managed by uninformed, mistaken, or wishful intent rather than by strict attention to acknowledged uneven-aged standards. Silvicultural interventions that are called "uneven-aged" should in fact be uneven-aged, so as to ensure long-term sustainability of stand structure and yields from the desired species.

There are two pitfalls that await the unwary forester who plans to implement a new or untested uneven-aged silvicultural system in a given stand. The first is that a system may be labelled "uneven-aged" when it is in reality even-aged. Foresters and landowners with long experience in even-aged methods may be tempted to incorporate even-aged features into a proposed uneven-aged system. The result may be that the uneven-aged character of the proposed system is compromised to the point where the system becomes essentially even-aged. This is especially critical on Federal lands, where compliance with existing management plans often depends on the age structure of the stands being managed.

The second concern is that a system may be labelled "uneven-aged" when it is in reality so-called "selective cutting" or "high-grading". This can be an insidious problem, in that several decades may pass before the ersatz "uneven-aged" method is found wanting. Further, though the ersatz "uneven-aged" system will ultimately be maligned as a failure, a properly-developed uneven-aged system might have been successful. If this leads foresters to reject

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"uneven-aged" methods as inappropriate for certain forest types based on the ersatz experience, when the technically precise implementation would have been successful, the craft of silviculture is not advanced.

We therefore propose a subjective decision model to help foresters determine whether a hypothetical silvicultural system is best identified as even- aged or uneven-aged. The model is based on commonly-accepted standards for the conduct of uneven-aged silviculture in North American forests and elsewhere, derived from both the historical and contemporary literature.

In order to consider a recommended prescription or silvicultural system as uneven-aged, all of the following standards must be achieved. This stance is certainly open to debate. However, the failure to achieve uneven-aged structure may not be immediately apparent, even over the course of several cutting cycles. Thus, our absolutist position ensures a conservative posture such that the uneven-agedness of the proposed system is assured. Deviations from the standards represent, in our view, uneven-aged silviculture at risk.

Standards

Cutting-cycle Versus Rotation

Even-aged silviculture is based on the rotation, defined as the length of time between stand regeneration and final harvest (Society of American Foresters 1987), usually occurring at or near the age when the dominant trees in the stand reach financial maturity. During the course of the rotation, silvicultural treatments are applied chronosequentially through the rotation, one treatment at a time. Conversely, uneven-aged silviculture is based on the cutting cycle, defined as the number of years between partial reproduction harvests. Many different silvicultural treatments are often imposed during a given cutting-cycle harvest, or are prescribed at given intervals during the cutting-cycle. Uneven-aged systems should be wholly unencumbered by the concept of rotation, relying exclusively on the cutting cycle as the operational unit of time.

Three Age Classes Versus One or Two Age Classes

In even-aged stands, trees of the desired species are the same age or age class, arising from a single major disturbance that affects the entire stand. Silviculturists allow for at most two age classes in an even-aged stand, to encompass a seedbearing or sheltering overstory. The difference between the oldest and youngest tree within an age class is arbitrarily established as not greater than 20 percent of the rotation age (Smith 1986). In uneven-aged stands, trees of the desired species occur in three or more distinct age classes arising from separate, small-scale disturbances. The difference in age between trees of mean age from the oldest and youngest age classes exceeds 20 percent of the mean age of the mature dominant tree at harvest.

However, apart from the formal definition, uneven-aged stands are characterized by a prominent lack of concern about the ages of the trees in the stand. Most operational decisions about manipulating individual trees are

Reverse J-shaped Curve Versus Bell-shaped Curve

The diameter distribution of the desired species component in an even-aged stand is a "bell-shaped" curve or a normal (or Gaussian) probability density function (Meyer 1930). Even-aged stands thus can have trees of different sizes, albeit of the same or similar ages; the variation in diameters increases over time. The diameter distribution of the desired species component in an uneven-aged stand approaches a reversed or inversed J-shaped curve, most commonly approximated by a negative exponential probability density function (Meyer 1943, 1952). The general structure of an uneven-aged stand is similar in concept to the diameter distribution that can be obtained by combining the normal curves from each stand within a fully-regulated forest of even-aged stands (Assmann 1970).

Multiple Crown Layers Versus Single Crown Layer

The crown profile of the desired species component in an even-aged stand is a single layer, or at most two distinct layers in stands that have two age classes, when measured across a vertical transect of crown height. The crown profile of the desired species component in an uneven-aged stand has foliage in many layers of the crown canopy, when measured across a vertical transect of crown height. The crown profile distributions may be the key variable in the identification of silvicultural regime.

Gap-phase Minor Disturbance Versus Stand-level Major Disturbance

Regeneration in even-aged stands mimics that which occurs following a catastrophic ecological event that removes most, if not all, of the previous stand. The species that colonize this seral secondary successional environment are typically fast-growing, intolerant of shade, and able to thrive in the nutrient-rich conditions that characterize this open microclimatic condition.

Conversely, regeneration in uneven-aged stands follows the pattern of gap- phase regeneration dynamics (Bray 1956, Pickett and White 1985), where the mortality of an individual tree or group of trees creates an opening in the canopy, beneath which the establishment and/or development of a small cohort of seedlings and saplings occurs. The dynamics of the regeneration in these gaps occur as a microsilvicultural "even-aged stand". The bigger the gap, the less likely that a tree will be affected by gap-bordering trees, and the more favorable conditions for intolerant species.

Treatment of Subunits within The Stand Versus The Stand As A Whole

The timing and spatial arrangement of applying silvicultural practices in uneven-aged stands are vastly different than in even-aged stands. In even-aged stands, a typical treatment, whether it be regeneration, site preparation, intermediate treatment, or reproduction cutting, is usually applied to the entire area at an appropriate time during the rotation. Conversely, in uneven-aged stands, individual silvicultural practices are

generally conducted either as a component of cutting-cycle harvests or timed in association with them. A given practice is typically conducted only within distinct subunits of an uneven-aged stand in any given cutting cycle. However, the full variety of silvicultural practices--regeneration, site preparation, intermediate treatment, and reproduction cutting--are commonly considered within each cutting cycle in every uneven-aged stand.

After a cutting-cycle harvest in an uneven-aged stand, a majority of the area is unsuitable for acquiring regeneration. This is the case simply because the majority of the growing space will be occupied with immature trees. Establishing regeneration beneath an immature stand is as illogical in uneven-aged silviculture as it is in even-aged silviculture.

Because regeneration is only required in subcomponents of the stand, the area in which site preparation is applied will be restricted as well. Efforts to impose site preparation across the entire stand will result in considerable wasted effort and expense. On the other hand, the few areas that require site preparation should unquestionably be treated. Thus, the best approach to site preparation in an uneven-aged stand is to have the entire stand subject to site preparation, but to only impose the treatment in those subunits of the stand where it is required.

In uneven-aged silviculture of both pines and hardwoods, release cuttings are thought to be the most critical element of intermediate treatment. This is because the research basis for successful establishment and development of regeneration in most uneven-aged stands is, with a few prominent exceptions, very tenuously established. If adequate regeneration of desired species is acquired, release treatments will probably optimize its development. Thus, herbicides will continue to play a key role in uneven-aged silviculture.

Just as improvement cuttings are commonly applied as the initial treatment in old cutover or mismanaged even-aged stands, so should they be the first cuttings conducted in cutover or mismanaged uneven-aged stands. The most likely candidates for improvement cutting are old even-aged stands under transition to uneven-aged structure. The suppressed or poorly-formed trees at the lower end of the normal curve are unlikely to respond to release, and represent poor growing stock upon which to rely. Similarly, large trees of low vigor that are at risk of mortality prior to the next stand entry should also be removed.

The major classification of thinning--low, crown, mechanical, free, and selection thinning (Smith 1986)--applies to uneven-aged silviculture as well as to even-aged silviculture. In any given cutting-cycle harvest, a forester will likely employ low thinning, crown thinning, mechanical thinning, and thinning of dominants in different parts of a given uneven-aged stand. A thinning with these different components in an uneven-aged stand should be called free thinning, as is a thinning with these different components in an even-aged stand.

Cut The Worst Trees And Leave The Best, Versus Vice Versa

An essential feature of the selection method is to employ some objective or subjective procedure whereby trees above some critical diameter

mit can be retained, and trees below the limit can be removed. Most actical methods of regulating uneven-aged stands must include this fea-re to improve the silvicultural condition of the residual stand. To alify as legitimate uneven- aged practice, some discrimination among the mature trees must occur such that the poorest are harvested during the tting cycle operations, and the best are retained (Troup 1928).

stainable Stand Structure Versus Unsustainable Structure

Uneven-aged silviculture depends on the successful acquisition of re-neration of the desired species. As in even-aged silviculture, "success-l" in application to regeneration has two components--adequate numbers d adequate distribution. The long-term success of uneven-aged silvicul-re in any given stand depends on whether enough seedlings and saplings n be acquired for proper development into the merchantable classes, ereby ensuring long-term sustainable yields from the stand.

Uneven-aged stands can exist in one of two regulatory configurations--ll-balanced stands or poorly-balanced stands. A well-balanced uneven-ed stand produces similar yields at each cutting cycle, sustainable over e long term. A poorly balanced (or irregular) uneven-aged stand produces elds that vary between cutting cycles, but which are sustained in the ng term. Poorly-balanced stands comprise the majority of uneven-aged ands, and will become more prominent as even-aged stands undergo transi-on to uneven-aged structure.

A failure to sustain long-term yields leads to "selective cutting." t, the term "selective cutting" itself is confusing, in that it has no nsistent silvicultural meaning among foresters or the general public. In s most common practice, "selective cutting" is an abusive cutting method at releases trees of poor form and slow growth. Because of the inconsis-nt meaning associated with this term, we advocate that its use be discon-nued in all but its negative silvicultural meanings.

lume or Structural Regulation Versus Area Regulation

The key to sustainability of uneven-aged structure is not the short-rm concept of balance but rather the long-term concept of regulation. thods of regulation are critical to the success of the method. Volume gulation, in which the allowable cut is based on the periodic increment er the preceding cutting cycle, has been shown to be effective in several ng-term cases in the United States (Pearson 1951; Reynolds 1959, 1969). ructural regulation, in which the allowable cut is based on an ideal tar-t stand structure, is a more recent development, though one in which ng-term success has yet to be conclusively demonstrated (Farrar and rphy 1989).

This offers a logical regulatory distinction between the methods. If a ttern of harvest is based on area regulation at the stand level, we sug-st that the method is in reality even-aged. On the other hand, if the rvest is conducted using volume control or structural control--even if e harvest is concentrated in a few large subunits of the stand--then we ggest that the system is in reality an uneven-aged selection system. Ef-rts at the stand level to combine area regulation with either volume con-ol or structural control simply add inefficiency, cost, and undue con-raint to a system that does not profit by the combination.

Summary

The ideas presented in this paper are intended to serve both as a of fundamentals for the application of uneven-aged silvicultural syste and as a point of departure for expanding the debate about the more poor understood details regarding those systems. Differences in interpretat among different foresters may lead to debate about the importance of hieving these standards, and it is the intent of this paper to foster s debate. If systems that deviate from these standards are proposed as even-aged, the proposers might do well to examine whether the deviati are not resulting either from an undue attention to short-term yields the expense of long-term sustainability of uneven-aged structure, or f an effort to retain some semblance of even-agedness out of convenience, erability, or other non-silvicultural considerations.

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INFLUENCE OF RESIDUAL SHORTLEAF PINE SEED TREES ON HEIGHT OF REGENERATION [1]

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Abstract. Total height, dbh and location of all shortleaf pine (Pinus echinata Mill.) saplings regenerated within a 25-ft radius of three shortleaf pine seed trees were recorded on a Ouachita Mountain site in southeastern Oklahoma. The ages of a subsample of the saplings were obtained. Total height and age, dbh, crown length and width, and radial increment since harvest were recorded for each seed tree. Regeneration density adjacent to the seed trees averaged 3,200 saplings/ac at 14 years of age. Sapling heights increased with increasing distance from the seed trees. Sapling diameters were not well correlated with proximity to the seed trees because of intense competition within the young stand. A regression model relating sapling height to distance from the seed tree indicated that total height of regeneration was reduced, on average, within 18.5 ft of the seed trees. Total volume of reproduction within the affected area averaged 1023 vs. 1256 ft^3/ac beyond the 18.5-ft radius, roughly a 20-percent difference. However, the existing 11 seed trees/ac influence only about 27 percent of an acre. This reduces the 20 percent volume loss to under 5 percent. In addition, the value of sawtimber volume added to the seed trees more than offset the growth loss of the sapling volume.

Introduction

Naturally regenerating southern pines can be an attractive option, especially on public and nonindustrial private forests. The public often perceives natural regeneration to be more consistent with multiple-use objectives. Private landowners, on the other hand, appreciate the lower up-front costs associated with this option. Forest managers use natural regeneration on one-third to one-half of the stands in which shortleaf pine (Pinus echinata Mill.) either predominates, or is mixed with loblolly pine (P. taeda L.). Of the three even-aged systems--clearcut, seed-tree, and shelterwood--the seed tree system is the one most widely used (Lawson 1986).

When contemplating the possibility of regenerating pine stands by the seed-tree method, one must answer several questions: (1) How many and what kind of seed trees should be retained? (2) If the seed trees are retained after regeneration occurs, will they suppress the developing stand or cause it to be overstocked? (3) Will the volume added

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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o the sawtimber-size trees more than compensate for the slower sapling rowth? (4) How valuable are the seed trees now, and what is their potenial value? (5) How feasible is a seed-tree harvest once the regeneration ecomes established? (6) What potential damage or benefit might a harvest ncur in the new stand (Grano 1961)?

There is little available information describing competition and growth elationships between seed trees and adjacent reproduction. Smith (1961) easured the total heights of 9-year-old longleaf pine (Pinus palustris ill.) seedlings associated with seed trees whose average crown radius was 1 ft. He found that seedlings within a 10-ft radius of the parent trees ere 45 percent as tall as those in a "competition zone" 20-30 ft out. eedlings located 10-20 ft from the seed trees were 70 percent as tall as hose in the outer zone. If a seed tree reduces reproduction growth within 25-ft radius, then reserving 10 such seed trees per acre may affect 45 ercent of the new stand.

Shortleaf pine stocking guides, which use the crown area of open-grown rees to estimate the maximum "growing space" a tree of given dbh requires Rogers 1983), may indicate the competitive influence seed trees have on heir offspring. For example, a 12-inch dbh tree requires 8.1 milacres radius: 10.6 ft) of growing space; a 14-inch dbh tree requires 10.6 milcres (radius: 12.1 ft), and a 16-inch dbh tree requires 13.5 milacres (raius: 13.7 ft).

This study attempts to provide a preliminary assessment of the competiive relationships between shortleaf pine seed trees and their reproducion. Forest managers should find this information useful when determining he role and fate of seed trees under this silvicultural system.

Methods

tudy Area

The study site is located on forest industry lands in southern Pushmaaha County, Oklahoma, near the southern edge of the Ouachita Mountains hysiographic province. It is north of the Gulf Coastal Plain and near the estern limit of the southern pines' natural range. Soils are mapped in he Sherwood-Zafra association, and are moderately deep to deep, well rained, and typified by fine sandy loam surface layers overlying sandy lay loam (Bain and Watterson 1977). The shortleaf pine site index for hese soils is an estimated 70 ft at 50 years.

Although past management records were unavailable, present conditions ndicate the stand was harvested approximately 14 years ago, leaving about 1 seed trees/ac. It appears a herbicide treatment has effectively conrolled most hardwoods. Post (Quercus stellata Wangenh.) and blackjack aks (Q. marilandica Muenchh.) are prevalent among the existing hardwoods. he stand needed precommercial thinning because of the over-abundant shorteaf pine regeneration.

ata Collection

The following variables were measured on three typical shortleaf pine eed trees: dbh, total height, crown length, crown radius in the four carinal directions, total age, and diameter increment since the last harvest.

Preliminary observation indicated that the radius of a seed tree's influence on sapling height was within 25 ft. Consequently, each sapling within 25 ft of a seed tree was mapped, and its total height and dbh recorded.

Data Analysis

Seed-tree cubic-foot volumes were determined from taper functions developed by Farrar and Murphy (1987). Board-foot volumes (Doyle), were derived from Mesavage and Girard volume tables, form class 78. By assuming that the saplings had a conical shape, groundline diameters were calculated using similar triangles. Cubic-foot volumes were then estimated using groundline diameters and total heights.

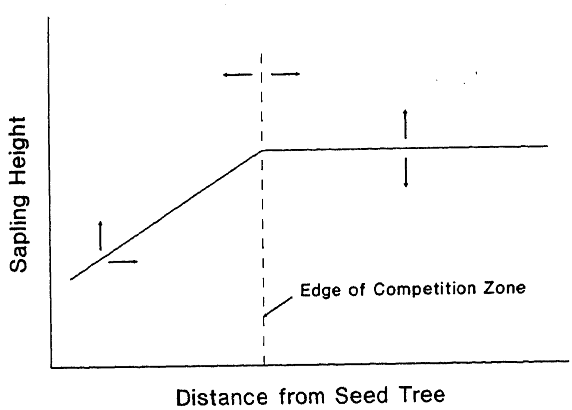

Figure 1. Example of a segmented-linear regression model relating sapling height to distance from the seed tree.

Several regression models were tested for their ability to relate sapling dbh, height, and volume to distance from the seed tree. A segmented-linear regression model with one joint point relating sapling height to distance from the seed tree was chosen to estimate the radius of the competition zone (Fig. 1). The model's interior segment consists of a simple linear regression line. The exterior segment is a horizontal line representing the mean height of trees beyond the competition-zone radius. The interior and exterior model segments were mathematically constrained to join at the competition-zone radius by transforming the data in the inner-segment model. These data were transformed by subtracting the competition-zone-radius distance from each inner-segment tree distance, and the outer-segment mean height from each inner-segment tree height. This made it possible to estimate the slope of the inner segment line using Statistical Analysis System (SAS Institute 1988) software for fitting "no-intercept" regression lines.

In fitting the segmented regression model, the sum of squared residuals (SSR) was obtained by adding the SSR for the sloped simple linear regression segment to the SSR about the horizontal mean line (equivalent to the total sum of squares corrected for the mean) comprising the outer segment of the model. The competition-zone radius of each seed tree was adjusted iteratively to find a minimum model SSR. The radius corresponding to this minimum was accepted as the estimate of the competition-zone radius for that seed tree.

Table 1. Description of seed trees.

Seed tree	Age	Dbh	Height	Crown length	Av crown radius
	(yr)	(inch)	----------	(ft)	----------
1	44	15.1	46	23	12.0
2	44	13.9	43	25	11.8
3	45	13.4	38	28	13.8
Mean	44	14.1	42	25	12.5

Table 2. Description of regeneration.

Seed tree	Sapling count	Average height	Average dbh	Average age
		(ft)	(inch)	(yr)
1	136	17.5	2.1	16
2	138	18.0	2.3	14
3	154	18.3	2.1	13
Mean	143	18.0	2.2	14

Results

Characteristics of the seed trees are described in Table 1. Based upon ortleaf pine stocking guides (Rogers 1983), the sample trees require an erage growing space of 11.6 milacres (equivalent to the area of a circle ving a 12.7-ft radius). The seed trees were about 30 years old when the plings became established. The regeneration around each tree contained ly minor openings and a small number of hardwoods (Fig. 2). An average 143 stems, or about 3,200/ac, were present within 25 ft of each seed ee (Table 2). According to Rogers (1983), a stand of trees with a 2.0-ch average dbh should have no more than 2,600 stems/ac; this further in-cates the stand's overstocked condition.

Diameters, being strongly density sensitive, were not well correlated th distance from the seed tree. In general, the saplings increased in ight with increased distance from the seed trees. At about 16-18 ft out, wever, the heights leveled off (Fig. 3). For any distance from a seed ee, the range of sapling heights exceeded 10 ft.

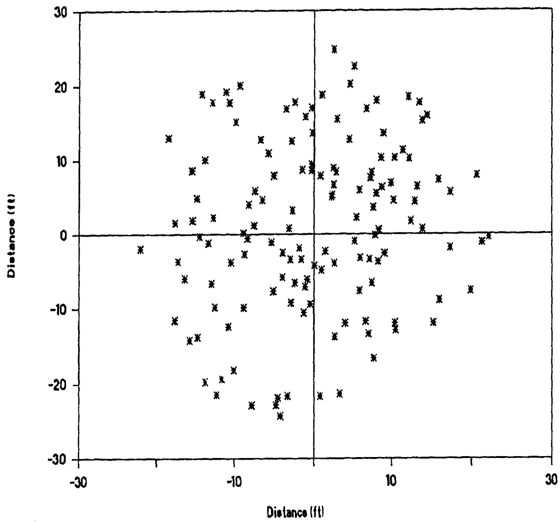

Figure 2. Distribution of regeneration within 25 ft of seed tree one.

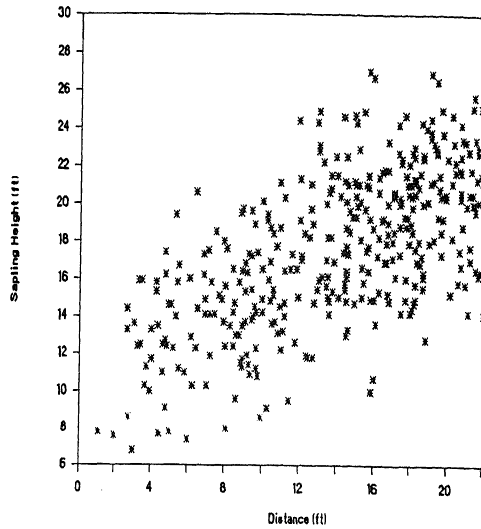

Figure 3. Relationship between s ling heights and distance from s tree (all seed trees combined).

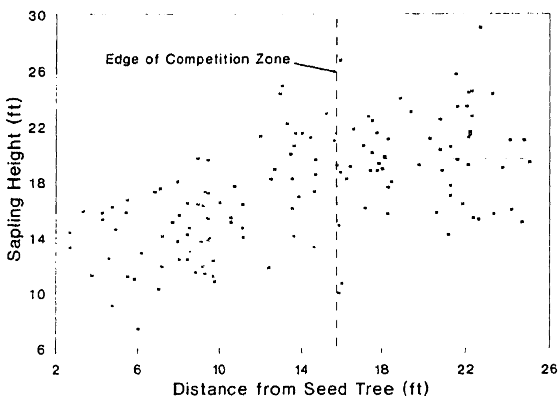

Figure 4. Segmented-linear regression model identifying the competition-zone radius of seed tree one.

Seed Tree-regeneration Competit Relations

Figure 4 illustrates the s mented-regression model for s tree one. The point at which two lines intersect denotes outer limit of the zone domina by the seed tree. The radius the competition zone averaged 1 ft for the seed trees in this st (Table 3). Proportion of to variation explained by the segm ted regression model was 0. 0.43, and 0.45 for seed trees o two, and three, respectively.

The saplings inside the c petition zones grew 1023 ft³/ while those outside the zones eraged 1256 ft³/ac. However, existing 11 seed trees influe only about 27 percent of an ac Hence, the true sapling growth l is approximately 63 ft³/ac (about 5 percent). This translates into a l of $7-8/ac at current local pulpwood stumpage prices. During the same p iod, the seed trees grew an estimated average 139 ft³, or 418 bd ft

4). This volume translates into a gain of $60-70/ac, more than com-
ing for the sapling growth loss.

Table 3. Volume accumulation inside and outside of the seed-tree competition zone.

Seed tree	Zone radius	Model ptv[1]	Sapling volume Inside	Sapling volume Outside
	(ft)		--- (ft^3/ac) ---	
1	15.8	0.38	983	988
2	22.8	0.43	1132	1476
3	17.0	0.45	953	1304
Mean	18.5		1023	1256

[1] Proportion of total variation explained by the segmented regression model.

Table 4. Seed tree growth during regeneration period.

Seed tree	Dbh[1]	Height[2]	Volume/ac:	
	(inch)	(ft)	(ft^3)	(bd ft)
1	2.5	13	164	528 [3]
2	2.6	15	151	440
3	2.4	7	101	286
Mean	2.5	12	139	418

[1] Measured from increment cores.

[2] Estimated from site index curves (Graney and Burkhart 1973).

[3] Doyle log rule.

Shortleaf pine seed trees suppress the height growth of adjacent saplings beyond the area covered by the seed tree crowns. On average, the volume of regeneration located inside the competition zone was about 20 percent less than that outside. However, considered on a per-acre basis, the loss dropped to about five percent. Also, the sawtimber value added to the seed trees more than offset the lost pulpwood volume growth.

Although shortleaf pine rotations of 60-70 years are typical, the seed trees observed in this study were only about 30 years old when the stand was harvested. Their average total height at that time probably was between 30-40 ft. Assuming a 50 percent live-crown ratio, the height to the base of the live crown was 15-20 ft. For several years after the harvest, the seed trees had little competition; hence, they self-pruned very few branches. At present, height to the base of the live crown averages 17 ft (Table 1). Had the rotation been lengthened, the seed trees' total heights and heights to the live crown might be 15-25 ft greater than those sampled in this study. The greater height of the crowns would allow more light to penetrate to the forest floor, significantly altering the competitive relationships observed in this study.

Land managers should attempt to quantify the potential value increase of seed trees when considering their fate. The cost of reentering the stand to harvest the mature trees may be greater than the financial return from their sale. However, if the young stand is grossly overstocked, salvaging the seed trees may provide a more cost-effective method of reducing sapling numbers.

Acknowledgments

Professional Paper No. P-3379 of the Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, OK 74078. The cooperation of Georgia-Pacific Corporation is gratefully acknowledged.

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STAND DEVELOPMENT FIVE YEARS AFTER CUTTING TO DIFFERENT DIAMETER LIMITS IN LOBLOLLY-SHORTLEAF PINE STANDS [1]

Paul A. Murphy and Michael G. Shelton [2]

Abstract. Three diameter-limit cutting treatments--12, 16, and 20 inches--were replicated four times on 1-ac net plots surrounded by a 66-ft isolation strip in loblolly-shortleaf pine stands (*Pinus taeda* L., *P. echinata* Mill.) located on the Crossett Experimental Forest in Ashley County, Arkansas. Hardwoods were treated before cutting with a soil-applied herbicide. An analysis of 5-year basal area, cubic volume, and board-foot volume growth showed no differences among treatments. The distribution of reproduction by seedling and sapling size classes did show trends by treatment. Tree basal area growth was related to pretreatment tree growth and the diameter limit that was imposed.

Introduction

Diameter-limit cutting is a potential harvest cutting technique for selection management. Unfortunately, it has been synonymous with highgrading, in which the better trees are harvested and the rest are left. True diameter-limit cutting is more properly defined as the removal of all trees above a certain diameter, regardless of their quality. Despite the opprobrium that diameter-limit cutting has received because of its association with highgrading, some evidence indicates that it might be a viable cutting method.

Literature Review

Trimble (1971) compared diameter-limit cutting, single-tree s ection, and clearcutting in Appa chian hardwoods on the Fernow perimental Forest in West Virgi The diameter-limit cuts varied tween 15.5 and 17.0 inches and eraged 16.6 inches. He conclu that diameter-limit cutting sh not be repeatedly applied to t hardwood stands because species c position is not as easily contro as in single-tree selection, cutting tends to concentrate on better quality trees (because qu ity is partly a function of si Moreover, merchantable growth ma reduced by: (1) volume deductio cull and other trees left below limit; (2) mortality of trees b the limit; and (3) understock (because stocking is not explici controlled). Trimble also conclu that diameter-limit cutting coul advantageously used as a first in unmanaged stands to remove c large residuals.

Smith and Lamson (1977) inves gated growth and development o 52-ac Appalachian hardwood stand the Fernow Experimental Forest a a one-time cutting to a 9-i

[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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iameter limit. Twenty-five years after the diameter-limit cut, sawlog olume was 7,425 bd ft/ac (International ¼-inch rule), and periodic annual rowth was 300 bd ft/ac. The result was a well developed young sawtimber tand. Smith and Lamson concluded that cutting left a pole-sized stand composed of trees that were in the intermediate or overtopped crown lasses) that responded well to overstory removal. However, an older stand ight not have responded as well.

Beck (1989) reported on selection thinning from above--a treatment simlar to diameter-limit cutting--in yellow-poplar (Liriodendron tulipfera .) on the Bent Creek Experimental Forest near Asheville, North Carolina. eck concluded that the method might be used to generate income (low thinings would not produce an operable cut) and leave the stand reasonably roductive, provided that trees in subordinate positions are capable of esponding to release.

According to Leak (1978), a stand will have a consistent structure and ield if a consistent cutting policy is followed. The structure and yield ay not be constant but may vary with a regular frequency. Although it has een suggested that diameter-limit cutting may have a long-term dysgenic ffect, there is no evidence to support that contention. However, diamet--limit cutting offers no opportunity to improve volume and quality of rop trees through improvement cuttings and thinnings.

Some regulation techniques in selection management use a modification f diameter-limit cutting. For example, the volume control method used to egulate stand structure (Reynolds 1959, 1969) involves the use of a guidng diameter limit as a criterion for marking a stand for cutting. The asal area-maximum diameter-q (BDq) technique of stand structure regulation Marquis 1978, Farrar 1981) specifies a maximum diameter class to be left n the residual stand. The concept of financial maturity of individual rees (Duerr, et al., 1956; Murphy and Guldin 1987) uses tree size and rowth rate. For a given diameter growth rate, a tree will reach a size at hich its marginal increase in value in percentage terms falls below the lternative rate. It should then be harvested.

The longest term research on diameter-limit cutting was the methodsf-cutting study conducted on the Crossett Experimental Forest in south rkansas. The effect of four different reproduction cutting methods--heavy eed-tree, selection, diameter-limit, and clearcutting--on the subsequent rowth and development of reproduction and growth and yield was investiated. Baker and Murphy (1982) reported on the 36-year results. The diaeter-limit treatment outranked the clearcut and selection treatments in erchantable cubic-foot volume production and outranked the clearcut for oard-foot production (Doyle rule). There were no significant differences etween diameter-limit cutting and the highest ranked treatments in volume roduction, either in cubic feet or board feet. The results indicate that f diameter-limit cuttings are done regularly and consistently in loblol-y-shortleaf pine stands (P. taeda L., P. echinata Mill.), the stands will ecover from the initial drastic reduction in growing stock and will prouce a sustainable harvest--provided the seed source is adequate and the ardwoods are periodically controlled.

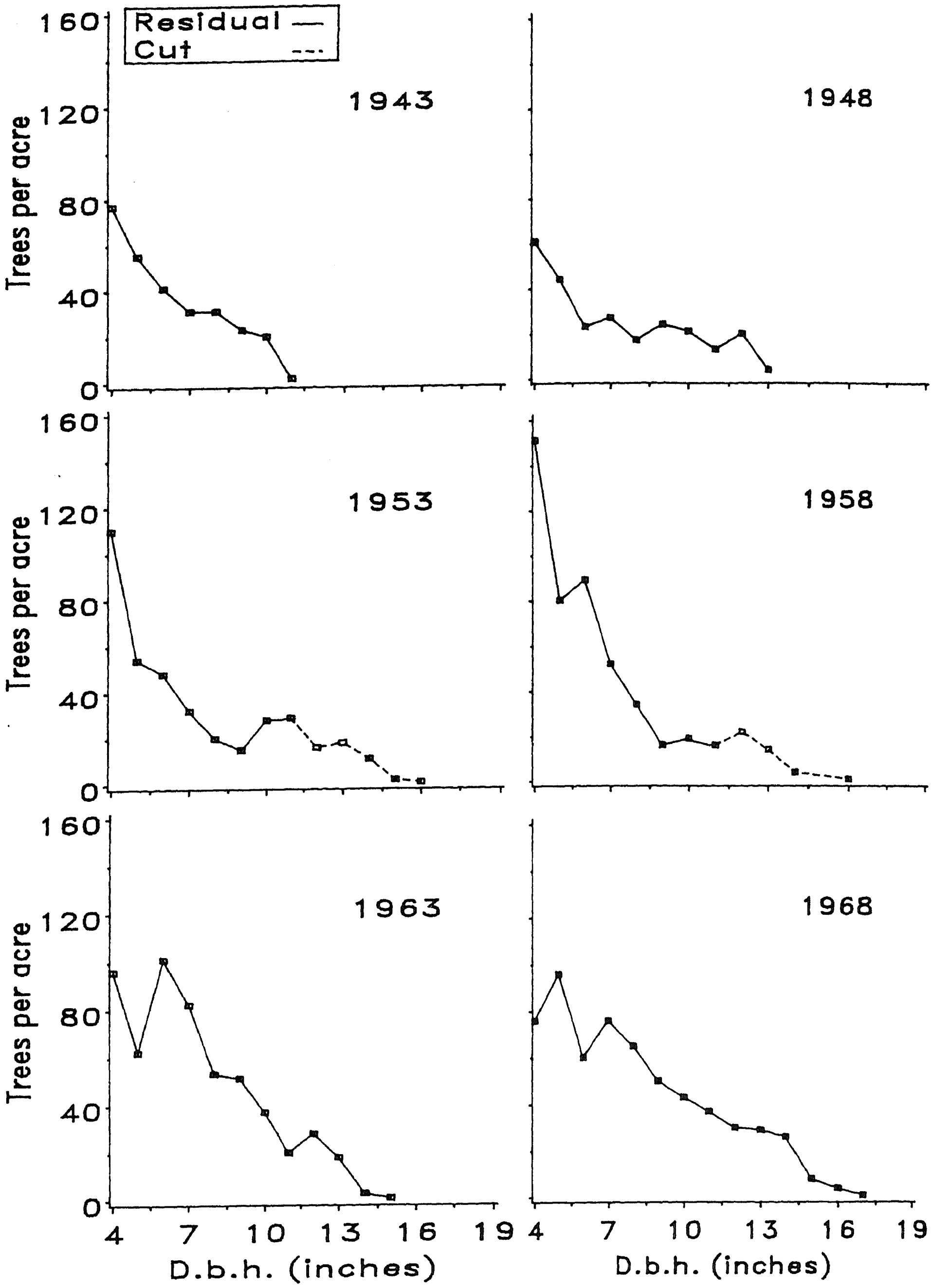

Figure 1. Stand structure by year for plot 64-2 of methods-of-cutting study, Crossett Experimental Forest, AR.

Figure 1 shows the stand development of one plot of the diameter-limit treatment of the Crossett Forest study through 1968. Unfortunately, the cutting practice on the diameter-limit treatment was altered in 1968, and the subsequent results are not indicative of a consistent diameter-limit cutting. Note that the residual stand gradually built up stocking and that reproduction was being recruited into the merchantable classes. The stand also had a good inverse J-shaped stand structure at the start. At least

ring this period, the results indicate that the plots subjected to diameter-limit harvest provided sustained harvests, albeit variable ones.

The results of these studies yield some tantalizing insights into stand dynamics. Most of the studies, however, investigated perhaps one diameter-limit treatment that was imposed just once or perhaps a few times. No study has investigated the effect of repeated application of different diameter limits to forest stands--especially in loblolly-shortleaf pine stands, which have a simpler composition and structure than hardwood stands and are more resilient than hardwoods to the detrimental effects of logging. Although the apparent efficacy of diameter-limit cutting is sometimes questionable and may be limited in application, such a study could provide an excellent insight into stand dynamics and the limitations of diameter-limit cutting as a standard practice.

With these objectives in mind, a diameter-limit cutting study was installed in loblolly-shortleaf pine stands in southern Arkansas in 1983. Presented here are the initial 5-year results.

Methods

The study plots are located in loblolly-shortleaf pine stands on the Crossett Experimental Forest in Ashley County, Arkansas. Average annual precipitation is 53 inches, and the soils on the study area are predominantly Bude silt loam (Glossaquic Fragiudalfs) with some Arkabutla (Aeric Fluvaquents) and Providence (Typic Fragiudalfs) silt loams. The stands have been under uneven-aged management with a cutting cycle of 3 to 9 years (Reynolds 1959, 1969). The last cut was in 1966, and the stands apparently lost smaller sized trees to suppression mortality during the 17 years of no activity prior to study establishment. The stands have thus assumed a more characteristic, even-aged stand structure. Furthermore, many of the trees have probably reached ages of 70 years or more. The stands before study installation in 1983 averaged--on a per acre basis--117 merchantable trees (3.6 inches dbh and larger), 104 ft^2 of merchantable basal area, 3,080 ft^3 of merchantable volume, and 12,192 bd ft (trees 9.6 inches dbh and larger, Doyle rule). The average site index was 96 ft for loblolly pine, base age 50 (Farrar 1975).

Treatments were 12-, 16-, and 20-inch diameter-limit cuts. For example, the 12-inch limit treatment harvested all trees 11.6 inches and larger. Each net plot is 1 ac of square dimension surrounded by a 66-ft isolation strip. The treatments were replicated four times in a randomized complete block design. Blocking was done by stand structure--that is, by the number of trees in the range of 3.6 to 9.5 inches dbh--to make the after-cut stand structures as homogeneous as possible.

Hardwoods were controlled in April 1983 prior to harvest by applying Velpar L™ at a rate of 3 lb/ac. The Velpar was diluted with an equal amount of water and applied on a 3- by 3-ft grid with spotguns that were calibrated to dispense 2.5 cc of herbicide-water mixture at each grid point.

The plots were harvested in August 1983 to the prescribed diameter limits. A 100-percent inventory of residual overstory pines 3.6 inches dbh

and larger by 1-inch dbh classes was conducted after logging. Indivi tree records were not kept. Volumes were computed using local volume uations (Farrar et al., 1984). Postharvest stand averages, by treatm are shown in Table 1. In addition, a seedling/sapling inventory was by systematically spacing 25 circular 0.004-ac subplots over the net p The size classes were the following: seedlings, 0.5 ft tall to 0.5 in dbh; 1-inch saplings, 0.6 to 1.5 inches dbh; 2-inch saplings, 1.6 to inches dbh; and 3-inch saplings, 2.6 to 3.5 inches dbh.

In February 1989, both overstory and seedling/sapling inventories conducted again using identical procedures to assess stand development ing the intervening 5 years. Plots were also cut to their prescribed ameter limits again if there was an operable cut of at least 1,000 b (Doyle rule) above the diameter limit.

An analysis of covariance was conducted using loblolly pine site i as a covariate. Periodic annual growth was tested for the following v ables: merchantable basal area, merchantable and sawtimber cubic feet umes, and board-foot volumes for the three principal log rules.

Two increment cores, located opposite each other on the bole, were en from two trees randomly selected in each 1-inch diameter class on plot during the spring of 1990. These cores were used to determine annual tree basal area increment, inside bark, during the 1979-83 pe prior to treatment and the 1984-88 period following treatment. These were used to assess the effect of the treatments on individual tree gro

Table 1. Residual stand characteristics, August 1983, and after years, February 1989, by diameter-limit treatment on a per acre basis

Variable	Diameter limit					
	12-inch		16-inch		20-inch	
	Year					
	1983	1988	1983	1988	1983	1988
Number of trees						
Submerchantable	3	2,967	5	2,092	0	1,824
Merchantable	39	33	74	66	86	80
Merchantable portion						
Basal area (ft^2)	16	19	45	51	86	90
Volume (ft^3)	378	509	1,233	1,449	2,580	2,731
Sawlog portion						
Cubic volume (ft^3)	118	276	787	1,015	1,986	2,160
Doyle (b.m.)	441	1,041	3,190	4,460	9,652	10,868
Scribner (b.m.)	561	1,490	4,488	5,955	11,968	13,156
Intl. ¼-inch (b.m.)	859	1,922	5,367	6,885	13,517	14,767

e following equation was fitted for this assessment:

$$\ln(I_a) = C_1 + C_2\ln(I_b) + C_3 \ln(B_r), \quad [1]$$

ere I_a = average annual tree basal area increment (ft^2), inside bark, after treatment (1984-88),

I_b = average annual tree basal area increment (ft^2), inside bark, before treatment (1979-83),

B_r = plot basal area per acre (ft^2), outside bark, of trees 3.6 inches dbh and larger, after the 1983 harvest, and

C_i = coefficients to be determined.

Results And Discussion

No significant differences were found for any of the growth variables ested. The growth was less than expected--averaging only 0.7 ft^2 for rchantable basal area and about 200 bd ft (Doyle rule-- Table 2). Lob- lly-shortleaf pine stands on these sites should produce an average of ft^2/ac annually of merchantable basal area growth and more than 300 bd ft oyle rule) of annual sawtimber growth.

Table 2. Periodic annual basal area and volume growth per acre by diameter-limit treatment, 1984-1988

Variable	Treatment			All treatments
	12-inch	16-inch	20-inch	
Merchantable portion				
Basal area (ft^2)	0.7	1.1	0.7	0.7
Volume (ft^3)	26	43	30	33
Sawlog portion				
Cubic volume (ft^3)	32	46	35	37
Doyle (b.m.)	120	254	243	206
Scribner (b.m.)	186	293	237	239
Intl. ¼-inch (b.m.)	212	304	250	255

One possible reason for the low growth is that the initial harvesting ccurred in wet weather. Some interim mortality might be attributed to gging damage aggravated by the wet weather. The harvest levels were also igh, and this undoubtedly contributed to some damage and resultant mortal- ty to the residual stand. Annual mortality rates averaged 1.3 trees/ac r the 5 years after harvest.

Another possible cause of low growth might be the lack of ingrowth. e residual stands have a very irregular structure with deficiencies in

the lower diameter classes (Fig. 2). An inverse J-shaped stand structure provides a continuous reservoir of trees that grow into merchantable classes. It will be some time before these stands exhibit such structure, because all the cutting is in the larger diameters, and there are no opportunities to mold the structure by cutting in classes below the diameter limit.

Tree age affects growth, and the advanced age of some of the trees might have contributed to lackluster growth for the past 5 years. Lack of vigor probably also contributed, because older trees are less vigorous than younger trees, and suppressed trees respond more slowly to release. The heaviness of the basal areas before cutting probably adversely affected the vigor of the residual stems.

The effects of residual basal area and past growth (an indicator of vigor) are demonstrated by the regression results for equation [2]:

$$\ln(I_a) = 1.1625 + 0.87769\ln(I_b) - 0.33690\ln(B_r), \qquad [2]$$

$$R^2 = 0.75, \text{ S.E.} = 0.3802.$$

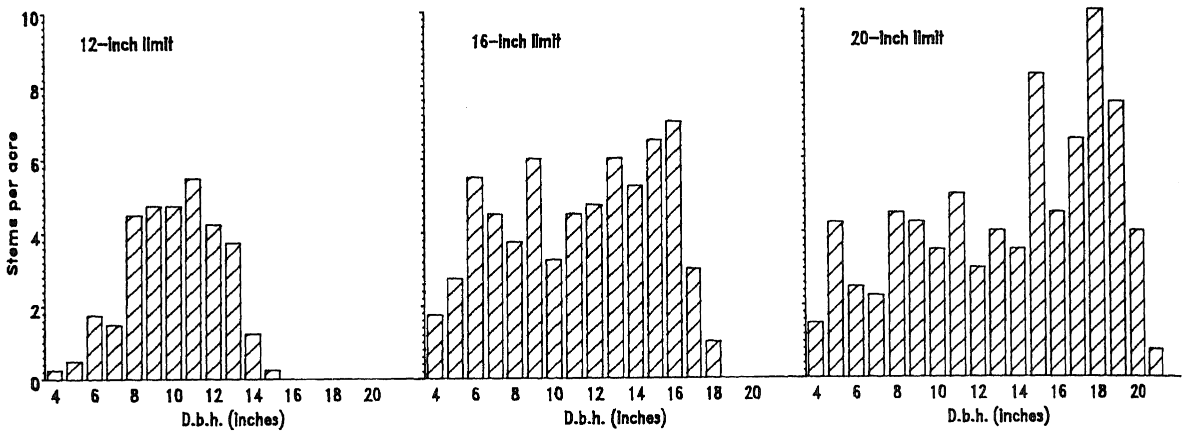

Figure 2. Composite stand structure by diameter-limit treatment, 1988, Crossett Experimental Forest, AR.

Note that the coefficient for the logarithm of tree basal area increment before treatment (I_b) is positive, indicating a positive relationship between the increment before and after treatment. The coefficient for the logarithm of stand density after treatment is negative--that is, a higher stand density will decrease individual tree increment. Hence, the regression results are consistent with generally held assumptions about tree growth dynamics in forest stands.

Solving equation [2] for a range of increments before treatment and for the average stand basal areas for each treatment after the initial diameter-limit cuts generates the values plotted in Figure 3. The plotted relationships illustrate two important factors that influence the response of trees to release--tree vigor and extent of release. Tree vigor is closely linked to growth rates--vigorous trees grow rapidly and nonvigorous ones

ow slowly. The extent of release is associated with the residual density ter the diameter-limit cuts; there is a fivefold difference in the resid-l basal areas of the 12- and 20-inch limits. The response of the 20-inch ameter limit is just somewhat above the growth experienced during the etreatment period. The response was greater for the 16-inch diameter mit, and the response of the most radical treatment was quite pronounced, ereby reflecting the drastic reduction in stand density associated with e 12-inch limit cut.

In the fall of 1983, a bumper loblolly pine seed crop of more than one llion sound seeds per acre contributed to the regeneration results (Fig. . The seedling/sapling stem count was 2,967/ac for the 12-inch limit; 092 for the 16-inch limit; and 1,824 for the 20-inch limit. The develop-nt of these submerchantable stems was particularly rapid for the 12- and -inch limits, where there were substantial numbers of 1-inch saplings. the 12-inch limit, the number of 1-inch saplings outnumbered the seed-ngs. This development is highly related to the residual densities, which re 16, 45, and 86 ft^2/ac of basal area for the 12-, 16-, and 20-inch lim-s, respectively. It is hoped that these seedlings and saplings will con-nue to develop and provide a future reservoir for ingrowth. However, ven the high basal area (90 ft^2/ac in 1988) of the 20-inch limit, the edling population on this treatment will likely be ephemeral.

Conclusion

The initial results of this study indicate the importance of stand dy-mics operating within uneven-aged silvicultural systems. Characteristics the overstory were found to have a pronounced effect on the amount and velopment of regeneration. The low overstory density resulting from the -inch cut favored establishment and rapid development of regeneration, ereas the higher density of the 20-inch limit retarded regeneration. ee vigor and extent of release had a strong effect on the response of sidual trees after cutting. Vigorous trees, which had high growth rates fore cutting, responded well to the reduced densities associated with the re drastic diameter-limit cuts. Tree vigor and the existing stand struc-re before the initial harvest were also related--the high initial stand nsity was reflected in the high degree of suppression and low number of aller trees in the stand. Tree mortality also undoubtedly influenced the itial results of this study, but interpretation of results was difficult cause only stand-level inventories were conducted. Clearly, positive ee identification and the associated measurements are needed to obtain a mplete picture of forest dynamics.

These initial 5-year results are not a definitive picture of the long-rm effectiveness of diameter-limit cutting. It is anticipated that more owth will occur as the stands recover from the effects of the heavy ini-al cut and assume more of a reverse J-shaped stand structure. Subsequent rvests will probably vary in quantity as the diameter-limit treatments rk through the existing stand structure. It will be some time before the ands have gone through a transient state and assume the character that eak (1978) describes.

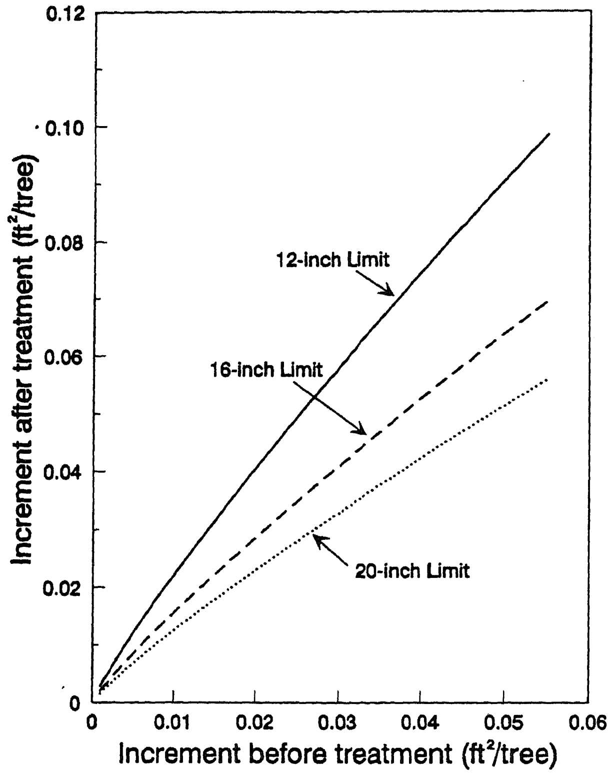

Figure 3. Annual basal area increment of individual trees, inside bark, as related to the increment before treatment and diameter limit.

Acknowledgment

This work was done in operation with the Departm of Forest Resources and Ark sas Agricultural Experim Station, University of Ark sas at Monticello.

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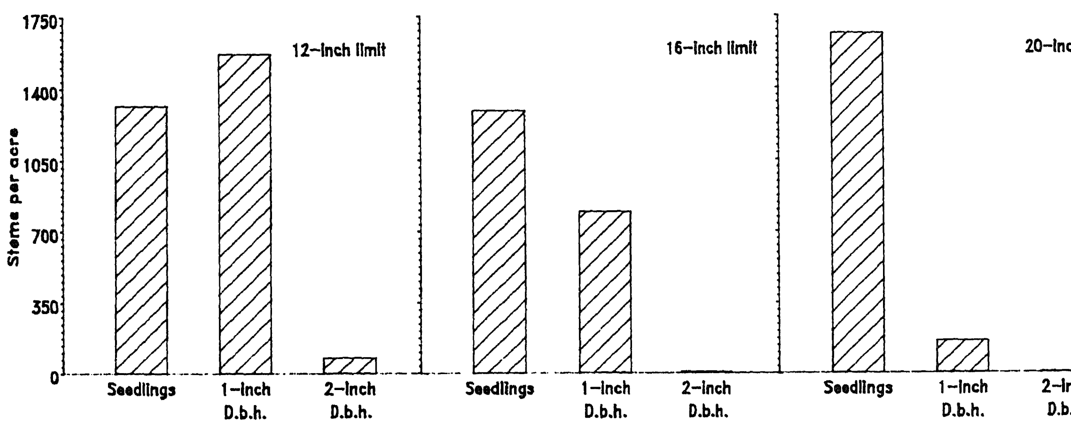

Figure 4. Number of seedlings and saplings by diameter-limit treatme 1988, Crossett Experimental Forest, AR.

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(OR, THE INADVERTENTLY BENEFICIAL ABUSE OF A
SILVICULTURAL FIASCO) [1]

Eric J. Schmeckpeper and Elizabeth M. Wellbaum [2]

Abstract. Since Tennessee Valley Authority began managing the Land Between The Lakes (LBL) National Recreation Area forest in 1964, foresters have been challenged to implement low cost silvicultural treatments which meet multiple use goals. In several two-storied stands with low quality, declining sawtimber overtopping 35- to 75-year-old poles, our solution was diameter limit cutting, as clearcutting was not acceptable. Examination of the cut stumps revealed a noticeable growth response 35 to 75 years earlier. From the quality of the sawtimber, we surmised that most of the poletimber originated after a previous "high-grade" cut had opened the canopy. We have applied this experience to the shelterwood system in managing most of the LBL forest. After the final removal cut, 10- to 20 ft²/ac of basal area/ac is retained. Adequate regeneration should develop with little effect from the sparse overstory, and residual trees reduce aesthetic impacts of the treatment. With this approach, we hope to effectively regenerate oak species (Quercus sp.) while addressing recreating visitor needs for less visually obtrusive forestry practices.

Introduction

This paper is based on observations of forest stand conditions and stand response to management at the Tennessee Valley Authority's (TVA) Land Between The Lakes (LBL) National Recreation Area. Since TVA began managing the LBL forest in 1965, its foresters have been continually challenged to find silvicultural practices which enhance native wildlife habitat, recreation opportunities, and timber resources, without degrading aesthetics. In other words, how can we do our work that no one notices we are her Foresters leave the universi equipped to fix almost any stand grow timber. However, on publ lands managed for many uses, li LBL, growing timber is frequen last on the list of reasons to ma age the forest. For instance, usual silvicultural fix for a sta of cutover, fire-damaged 70-year-o scarlet oak (Quercus coccinea) wou be a clearcut followed by natur hardwood regeneration, which to might not be an option. Clearcu ting in LBL has been held to a mi imum, used primarily to create 5- 15-ac patches of young growth with the 155,000 ac of mostly sawtimbe sized trees. In stands that ha needed regenerating, we have exper mented with intermediate cutting delayed release harvests, and shelterwood system.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

[2] Foresters, Tennessee Valley Authority, Land Between The Lakes, Golden Pond, KY.

Shelterwood System

In multiple-use forest management, we feel that the shelterwood system fers far more options for even-age management than does the single re- val clearcut. In the past 10 years, we have observed that most of the rvesting practices used in LBL accomplish some stage of the classical elterwood. Improvement-type cuts that left a sawtimber stand with about percent stocking served the purpose of a preparatory cut, opening the nopy sufficiently to stimulate seed production and some regeneration be- re the canopy closed again. Most LBL timber harvests are of this type. e 7-year forest management cycle we use allows for two or three cuts in a and to successively open the canopy over 21 to 28 years.

A problem with the shelterwood system is the final removal cut. To the erage hiker, hunter, or environmental activist, a shelterwood removal rvest bears a striking resemblance to a clearcut. In today's politically arged atmosphere, if we cannot use clearcutting or even something that sembles a clearcut, what can we do to ensure that even-age forests are generated?

Delayed Release Harvest

A condition encountered frequently in the late 1960s and early 1970s s the two-storied stand, composed of declining, large-diameter sawtimber ees overtopping small poles. The poles were from 35 to 75 years old. Re- arch generally indicated that attempting to manage old poles was a bad t due to epicormic sprouting and poor response (Roach and Gingrich 1968), en though the poles appeared to be of better form than the sawtimber. e sawtimber trees, on the other hand, were merchantable and the poles re not. Also, enough "multiple use" had become ingrained to make dis- steful the prospect of spending money to kill nice looking, straight oak les left after harvesting the sawtimber. The treatment implemented in ch cases was in practice a diameter-limit cut. Almost all the sawtimber ees were cut, or in some cases injected with 2,4-D. We termed this op- ation "delayed release" cutting because the poles were much larger and der than the saplings released in classical liberation cuttings (Smith 52).

Aesthetically, the pole stands were far superior to new clearcuts. The , loggers, accustomed to odd requests by then, attempted to minimize idder damage to the little "leftover" trees. Silviculturally, we might ve created a monster composed of old, slow-growing poles that would have sponded poorly, if at all. However, examining the cut stumps turned up a ue to the origin of the poles: something had caused a noticeable growth sponse in the sawtimber trees when they had been about pole sized, from to 75 years before, depending on the individual stand. Prior to TVA nership, much of the LBL forest had been high-graded. Digging back rough the scanty land records confirmed that "selective" sales of stave gs had occurred in the vicinity of our delayed release stands. The smal- r, less desirable stems left after high-grading probably became the lar- r, less desirable stems we later cut. The earlier cut had essentially

removed the canopy, which allowed enough light to the forest floor to stimulate the establishment and growth of oak seedlings and sprouts. Most were free to grow and spaced closely enough to deter side branching.

In 1986, a student intern revisited five of the stands that had been released between 1969 and 1975. Compared with an uncut stand, the released poles (aged 35 to 75) averaged a 55 percent increase in diameter growth for the 10 years following release. Unreleased stems in the control stand averaged a 2-percent increase in growth rate for the same period of time (Nelson 1986). Minckler (1957) found that releasing 35- to 100-year old white oak (Q. alba) poles resulted in a 46-percent increase in diameter growth. Armed with a little information, we felt considerably better about the prospects of delayed release cutting.

The Accidental Shelterwood

We observed that the silviculturally odious practice of high-grading had led to the establishment of another stand of acceptable quality oaks. The few residuals remaining after such a harvest evidently did not hinder regeneration. Even at an advanced age, regeneration appeared to respond favorably to release. Was the high-grade operation of many years ago essentially an accidental shelterwood? The question we needed answering was: "How long after the seed cut can the final shelterwood removal be postponed?" In our experience, a basal area of about 30 to 35 ft^2/ac remains following the preparatory and seed cuts. Adequate stocking of oak regeneration occurs within 2 to 3 years after the seed cut (Schmeckpeper et al., 1989). The overwood could be removed in 4 or 5 years during the next management cycle with full assurance of stand regeneration. Or, we might wait 35 to 75 years for the final removal until the regeneration "stems" look like "trees" to the general public, as with the pole stands discussed previously.

Our intent is to apply a compromise between these approaches. By the time the stand is ready for final removal, regeneration should be in place and at least of large sapling size (2-6 inches dbh). We will retain from 10 to 20 ft^2 of basal area in pole- and sawtimber-sized trees following final shelterwood removals. Except for den trees which have always been retained in LBL, the residuals will be merchantable quality trees. Regeneration should continue to develop under the sparse overstory. In time, it may be possible to return to the stand to remove the large trees, but their main function is aesthetic. Their purpose is to ease the transition between the young, even-age forest and the mature forest people are accustomed to seeing.

Managerial Considerations

We recognize that the intentional creation of a two-storied stand may not be an appropriate solution for many forest managers. Also, our applications need considerably more time and study to address the unknowns. We are tracking selected stands to be able to attach research results to these hypotheses. Certain problems with this approach should be considered:

Retention of some merchantable trees will reduce the value of timber sales. Marketing less volume could be a problem in many areas.

Epicormic sprouting will occur to some extent when boles are exposed to sunlight, especially after the second cutting. Hence, some timber value will probably be lost if the highest quality trees are not cut until the final removal. Depending on market conditions, it may be desirable to take the highest quality trees in the second cutting, after they have provided some seed, but before they are at risk for logging or epicormic damage.

We do not know if height growth is significantly affected by retaining the sparse overstory for a long period. The studies cited indicated that diameter growth responds favorably to delayed release, even in trees as old as 75 to 100 years.

If species composition is of concern, take care to ascertain that the poles being released are white oak rather than post oak (_Q. stellata_). The stands we surveyed in 1986 showed that post oak and hickory (_Carya_ spp.) had the lowest growth response. Northern red oak (_Q. rubra_), white oak, and black oak (_Q. velutina_) responded far better.

Time and careful study will determine if the practices we have describ- will allow us to meet the public's expectations of how a forest must , while still providing the wood resource people continue to demand. ould greatly appreciate hearing the insights of other forest managers orking toward these frequently conflicting goals.

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PINE-HARDWOOD REGENERATION IN SMALL OPENINGS FOR UNEVEN-AGED MANAGEMENT [1]

Thomas A. Waldrop [2]

Abstract. Uneven-aged management of pine-hardwood mixtures may prove acceptable for providing desirable combinations of timber and nontimber resources if these mixtures can be regenerated in small openings. Several combinations of opening size and degree of hardwood control were examined in a low-quality Piedmont hardwood stand. After one growing season, 80 percent of planted pines survived and most had doubled in height and remained free to grow. Hardwood regeneration was taller than pines in all treatments but was most vigorous in 1/3-ac openings where residual stems were felled and no herbicide was applied.

Introduction

Pine-hardwood mixtures are gaining acceptance for improving the productivity of low-quality hardwood stands while maintaining other values such as aesthetics, wildlife habitat, and species diversity. Pine-hardwood regeneration should be attractive to private nonindustrial landowners because it is generally less expensive to obtain than pine (Phillips and Abercrombie 1987). In the Piedmont Plateau and Appalachian Mountains of the Southeastern United States, 26.8 million acres of commercial forest land are occupied by hardwood or mixed pine-hardwood stands (Bechtold and Ruark 1988). Private nonindustrial landowners who control 72 percent of these stands generally ignore opportunities to convert to pine because of the expense, objections to clearcutting, or preferences for nontimber resources (Haymond 1988). Given limited options, most of these landowners choose to leave their woodlands unmanaged.

The USDA Forest Service is mandated by law to manage the National Forests to meet the goals of society as determined by the forest planning process. Under the New Perspectives Program, nontraditional forest management systems will be tried. Lower timber production will be accepted to favor other resources such as diversity, wildlife habitat, and aesthetics. Uneven-aged management is being tested on several National Forests and may become more common on others. Most research on uneven-aged management in the South has dealt with hardwood stands and with loblolly (Pinus taeda L.) and shortleaf pine (P. echinata Mill.) stands. Uneven-aged management of pine-hardwood mixtures may be attractive for nonindustrial private and national forestland. However, supporting research is limited.

Single-tree selection has not proven successful for regenerating oaks and other desirable upland hardwood species of intermediate shade tolerance (Sander et al.,

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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1983, Della-Bianca and Beck 1985). Group selection can be successful if there is adequate advance regeneration or small trees are felled for coppice (Sander 1988, Smith 1988). Development of hardwood regeneration is largely dependent on opening size, aspect, and site quality (Minkler and Woerheide 1965). Young hardwoods closer to the edge of openings than a distance equal to the height of border trees grow slower than those closer to the center. This pattern may be less pronounced on south-facing slopes which receive more direct and indirect sunlight (Minkler et al., 1973). Openings of ½- and 1-ac have proven satisfactory for plantings of red pine (*P. resinosa* Ait.), jack pine (*P. banksiana* Lamb.), and white pine (*P. strobus* L.) (Tubbs 1978). However, this technique has not been tested for southern pines or mixtures of pines and hardwoods.

The proportion of pine regeneration in a small opening in a hardwood or mixed pine-hardwood stand will likely depend on the pine species, the size of opening, and the degree of hardwood control. Loblolly pine seedlings are shade tolerant, but require more light as they get older (Brender 1973). Past research on regenerating pine-hardwood mixtures in clearcuts indicates that loblolly pine seedlings tolerate shade and other forms of competition on medium- to poor-quality sites. Most loblolly pine seedlings survive and overtop neighboring hardwood sprouts within 5 years (Waldrop et al., 1989; Evans 1990). These studies indicate that mixtures of upland hardwoods and loblolly pine may be regenerated successfully in small openings, particularly on medium to poor sites and on south-facing slopes.

This paper documents early results of an attempt to convert an uneven-aged low-quality Piedmont hardwood stand to an uneven-aged mixture of pines and hardwoods. Small openings were created throughout the stand to establish areas for management by group selection. Several opening sizes and levels of hardwood control were tried. Amounts of pine and hardwood regeneration present at the end of one growing season are reported here.

Methods

In 1989, six treatment combinations were replicated three times in a randomized complete block design. Treatments included two opening sizes and three levels of hardwood control. Opening sizes of 1/3- and 1/10-ac were chosen because of the relationship of opening size to the height of border trees discussed by Minkler and Woerheide (1965). Circular openings of 1/3-ac have a diameter of approximately two tree heights (136 ft), while the diameter of 1/10-ac plots (74 ft) is approximately equal to one tree height. Levels of hardwood control included: (1) chainsaw felling of residual stems over 6-ft tall; (2) chainsaw felling of residual stems plus application of Garlon™ 3A to all stumps; and (3) no control. Replicates were blocked across the slope (upper, middle, and lower) to remove site differences. Analysis of variance and linear contrasts were used to test for treatment differences at the 0.05 level of confidence.

The study area is in the Upper Piedmont of South Carolina on a 27-ac tract of the Clemson University Experimental Forest in Pickens County. Slopes range from 6 to 10 percent with a uniform southwest exposure. Soils

are severely eroded clay loams of the Cecil series. These soils have fertility because past land management practices led to erosion of top (USDA Soil Conservation Service 1972). Site index at age 50 years is 7 for loblolly pine and approximately 60 ft for upland oaks.

In 1989, this hardwood stand was all-aged with tree ages as high as years, and there was a wide range of dbh classes. White oak (Quercus L.) was the most abundant overstory species, representing 41 percent of stems and 30 percent of the basal area (Table 1). Other common overs species were black oak (Q. velutina Lam.) and loblolly pine. Common un story species were dogwood (Cornus florida L.) and hickory (Carya s Basal area was 73 ft^2/ac in 1989.

Prior to 1974, the stand was an unmanaged oak-loblolly pine mix with an average basal area of 100 ft^2/ac (75 percent hardwoods and 25 cent pine). During that year, all pines of commercial size were harves Today, abundant natural regeneration of loblolly pine occurs throughout stand in small openings created by the harvest. This regeneration may dicate that loblolly pine seedlings can survive in small openings where direct sunlight is provided by a southwestern exposure. Study plots located away from patches of heavy pine regeneration to minimize variat

Prior to treatment installation, the diameters of all trees 2.5 in dbh and larger were measured. Increment cores were extracted from a sa of 150 trees to examine age distribution. Sample trees were selected the range of dbh classes and distributed throughout the stand. The r tionship of age to dbh was determined with simple linear regression.

Trees were harvested on the 1/3- and 1/10-ac treatment plots in De ber 1989. All trees over 4.5 inches dbh were felled and limbed on sit research crews. Logs were skidded from the plots by a commercial logge February 1990. To minimize damage to standing trees, skidder opera were requested to use logging roads and skid trails established for 1974 harvest.

Hardwoods were controlled in early March 1990, immediately after ging. All residual stems over 6-ft tall were felled by chainsaw in 1 the 18 study plots (two opening sizes x three control treatments x t replications). Garlon 3A was applied to all hardwood stumps in half of plots where residuals were felled. The herbicide was applied at strength with no water. Hardwood control was not attempted in the rem ing six openings. In these plots, the basal area of residual stems a aged 10.8 ft^2/ac. For all residual stems, horizontal crown spread was timated by averaging the distance from the bole to the outer edge of crown in each of the four cardinal directions. Crowns of residual s covered an average of 30 percent of each opening. Genetically-impr loblolly pine seedlings were planted by research crews in each opening ing the first week of March 1990 at a spacing of 12 x 12 ft.

The location of each planted pine was mapped to monitor the relat ship of position within a plot to survival and growth. Each pine was lied as alive or dead in all plots on the first day of each month from ril through September 1990. Total seedling height and the height at

Table 1. Mean number of stems and basal area per acre before harvest by species group and size class.

Species group	Stem dbh class (inches) 2.5-5.4	5.5-9.4	>9.4	Total (percent)
	(stems/ac)			
Oaks				
White	56.3	11.6	14.6	82.5 (41)
Black	9.6	4.5	3.1	17.2 (9)
Scarlet	3.9	2.0	3.3	7.6 (4)
Post	1.8	2.6	4.2	8.7 (5)
Southern red	3.1	1.2	3.3	7.6 (4)
Misc.	0.1	0.1	0.0	0.3 (<1)
Total	74.9	22.1	28.6	125.5 (63)
Other hardwoods				
Yellow-poplar	1.5	0.6	1.2	3.3 (2)
Hickory	9.7	4.8	3.5	18.0 (9)
Dogwood	22.7	1.9	0.3	24.9 (12)
Misc.	10.8	2.3	0.4	13.6 (7)
Total	44.7	9.6	5.4	59.8 (30)
Pines				
Loblolly	2.6	5.9	4.3	12.9 (6)
Shortleaf	1.2	0.0	0.0	1.3 (1)
Virginia	0.1	0.1	0.0	0.3 (<1)
Total	4.0	6.1	4.4	14.4 (7)
All species	123.7	37.8	38.3	199.8(100)
	Basal area (ft^2/ac)			
Oaks				
White	1.3	3.4	17.2	21.9 (30)
Black	0.2	0.8	4.3	5.3 (7)
Scarlet	0.3	0.6	4.7	5.6 (8)
Post	0.2	0.8	4.3	5.3 (7)
Southern red	0.3	0.3	4.7	5.3 (7)
Misc.	0.0	0.0	0.1	0.1 (<1)
Total	3.0	6.4	36.8	46.2 (63)
Other hardwoods				
Yellow-poplar	0.1	0.2	2.2	2.5 (3)
Hickory	0.9	1.2	3.6	5.7 (8)
Dogwood	1.8	0.3	0.3	2.4 (3)
Misc.	1.0	4.8	1.6	7.3 (4)
Total	3.8	6.5	7.7	17.9 (25)
Pines				
Loblolly	0.3	1.9	4.1	6.3 (9)
Shortleaf	2.4	0.0	0.0	2.5 (3)
Virginia	0.0	0.0	0.0	0.1 (<1)
Total	2.7	1.9	4.1	8.9 (12)
All species	9.5	14.8	48.7	73.0(100)

year's node were measured at the end of the growing season. Growth was calculated as the difference between the two height measurements. During the September survey, the percentage of the crown of each seedling that was directly covered by nearby vegetation was estimated. Categories included 0, 1-25, 26-50, 51-75, and 76-100 percent covered. Seedlings were considered free to grow if no more than 75 percent of the crown was directly covered by competing vegetation and the terminal bud was not covered. Cover by residual stems over 6 ft tall was not included in estimates of direct cover.

Species composition and growth of hardwood regeneration were measured in September 1990. Circular sample plots, 0.001 ac in size, were established in a systematic pattern over each opening. A total of 50 sample plots was used in 1/3-ac openings, while 15 plots were used in 1/10-ac openings. Both samples represent 15 percent of the opening size. All seedlings and sprouts were tallied by species. Height was measured to the nearest 0.1 ft. In sprout clumps, all sprouts were counted, but height was measured only on the dominant sprout.

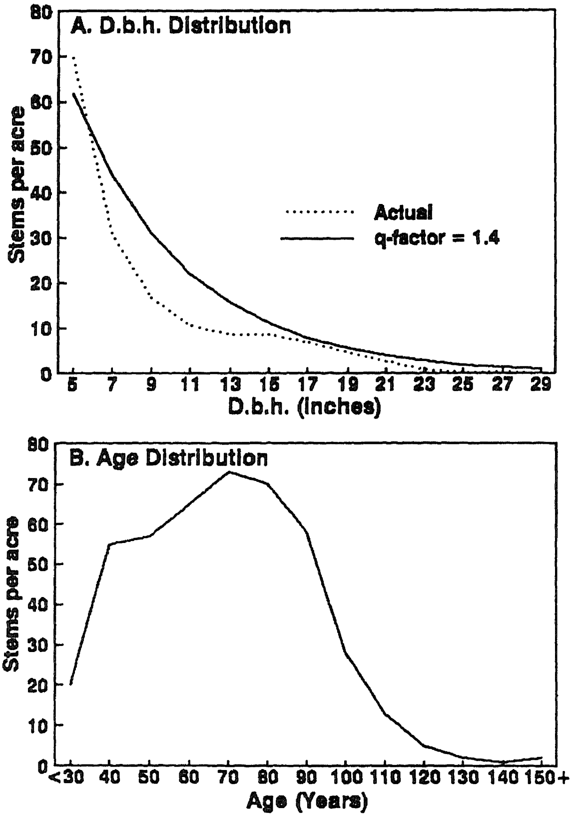

Figure 1. The dbh (a) and age (b) distributions of a Piedmont hardwood stand before harvest.

Results And Discussion

The dbh distribution of the stand prior to harvest was a reverse-J pattern, with large numbers of small trees and fewer large trees (Fig. 1a). This distribution had a q-factor of approximately 1.4, which is within the range Smith (1986) described acceptable for managed uneven-aged stands. A condition that must be met when single-tree selection is based on diameter is that dbh is closely correlated with age. Otherwise, fast-growing young trees may be selected for harvest, resulting in high grading of the stand. In the study stand, dbh was not well correlated with age (R^2=0.42). There were too few stems in age classes younger than 70 years (Fig. 1b). Under the observed conditions group selection may be a better choice than single-tree selection because trees of all dbh and age classes are harvested. Thinning of the residual stand, which would normally be done under group selection to create a reverse-J dbh distribution, was not necessary.

Natural regeneration of pines occurred infrequently. Survival of planted pines remained high throughout the first growing season for all opening sizes and levels of hardwood control. Survival at the end of the growing season was somewhat higher in 1/10-ac openings (86 percent) than in 1/3-ac openings (80 percent), but the difference was not statistically significant. Also, survival was not affected by level of hardwood control. At the beginning of May, all seedlings in 1/10-ac openings were alive but some mortality had occurred in 1/3-ac openings. This difference did not persist through later months, however.

Mortality of planted pines was greatest from early June through early August (Fig. 2), the driest period of the 1990 growing season. In 1/3-ac openings, seedling mortality was most common in the center and northwest quarter of study plots, which are the areas that received most direct sunlight. Mortality in 1/10-ac openings, which received less direct sunlight, was randomly scattered throughout the plot. These patterns may indicate that pine seedling mortality during the first growing season was associated with moisture stress rather than shading or other forms of competition.

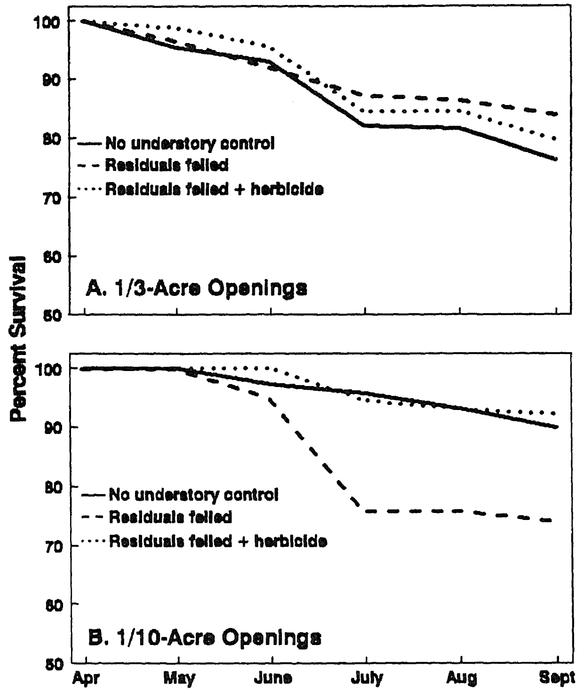

Figure 2. Mean monthly survival of planted pines by hardwood control treatment in 1/3-ac (a) and 1/10-ac (b) openings.

Total height and growth of planted pines appeared to be greater in 1/3-ac openings than in 1/10-ac openings (Table 2), but differences were not significant. Seedling height growth averaged 0.64 ft in 1/3-ac openings and 0.56 ft in 1/10-ac openings. No differences due to level of hardwood control were observed. Approximately 70 percent of all surviving pines remained free to grow at the end of the first growing season (Table 2). Although the portion of free-to-grow pines was somewhat higher in 1/10-ac openings, differences between treatments were not significant.

Species composition of hardwood regeneration was somewhat different than that of the preharvest stand, but it did not vary among treatments (Table 3). Rather than white oak, which was dominant before harvest, regeneration consisted of even mixtures of sprouts of black oak, scarlet oak (Q. coccinea Muenchh.), white oak, black cherry (Prunus serotina Ehrh.), blackgum (Nyssa sylvatica Marsh.), dogwood, and hickory. Seedlings of yellow-poplar (Liriodendron tulipifera L.) were also abundant.

Table 2. Mean height, growth, and portion free-to-grow for planted pines surviving one growing season.

Treatment	Height	Growth	Free to grow
	------ ft ------		- percent -
1/10-ac openings			
No understory control	1.2	0.6	70.7
Residuals felled	1.0	0.6	78.1
Residuals felled + herbicide	1.1	0.6	68.3
1/3-ac openings			
No understory control	1.2	0.6	68.2
Residuals felled	1.2	0.7	69.0
Residuals felled + herbicide	1.3	0.7	67.7

Table 3. Species composition of hardwood regeneration by treatment.

Hardwood species	1/10-ac openings No control	1/10-ac openings Fell	1/10-ac openings Fell and herbicide	1/3-ac openings No control	1/3-ac openings Fell	1/3-ac openings Fell and herbicide
	(stems/ac)					
Black oak	57	177	247	191	107	183
Scarlet oak	130	190	177	210	160	209
White oak	263	127	300	327	244	544
Misc. oaks	23	20	14	0	7	17
Black cherry	70	137	127	194	138	176
Blackgum	63	0	147	174	244	161
Dogwood	403	233	117	311	912	546
Hickory	233	500	263	182	458	312
Yellow-poplar	212	329	103	43	113	153
Misc.	351	78	157	77	37	133
Total	1,340	1,420	1,680	2,177	2,690	2,406

Vigor of hardwood regeneration was affected by both opening size and level of understory control. For the oak and all-hardwood categories, the number of sprouts per cut stump was greater in 1/3-ac openings than in 1/10-ac openings (Table 4). Within the 1/3-ac openings, sprouts per stump were most numerous where residuals were felled but no herbicide was applied. In plots where residuals were not felled, sprouts originated from

stumps of the trees of commercial size which were harvested. These mps were from older trees and had less sprouting capabilities than mps of felled residuals. In plots where residual stems were felled and bicide was applied, the herbicide did not kill the entire stump and root tem, but did reduce the number of sprouts produced. This pattern agrees h the results of Lewis et al. (1984), who found that a winter applican of Garlon 3A to the stumps of Piedmont hardwoods killed only a portion the stumps but effectively controlled sprout growth. Although support- data were not collected, sprouts in plots where herbicide was applied eared to be of better form than those in areas where herbicide was not lied. These sprouts tended to originate from below- ground buds while se in other areas originated from the above- ground cambium.

able 4. Mean number of sprouts per stump by treatment and species roup.

reatment	Oaks	Other hardwoods	All hardwoods
	------------- (number) -------------		
/10-ac openings			
No understory control	1.2a[1]	2.5a	1.9a
Residuals felled	1.7a	2.4a	2.0a
Residuals felled + herbicide	1.8a	1.7a	1.7a
1/3-ac openings			
No understory control	2.2ab	2.3a	2.3a
Residuals felled	3.3 b	4.0 b	3.7 b
Residuals felled + herbicide	2.4ab	2.7ab	2.4a

Means within a column followed by the same letter are not significantly different at the 0.05 level.

Height of the dominant sprout in each clump was also affected by open- size and level of hardwood control (Table 5). Sprouts tended to be ler in 1/3-ac openings than in smaller plots because a larger portion of hardwood regeneration was unaffected by competition from border trees. difference was significant for the other hardwood and all-hardwood spe-s groupings. This finding agrees with that of Minkler and Woerheide 65) who showed that the vigor of hardwood regeneration increased with tance from the edge of the opening.

For all treatment combinations, hardwood sprouts were taller (Table 5) n the mean height of planted pines (Table 2). This difference was atest in 1/3-ac openings where residuals stems were felled and herbicide not applied. Within the all-hardwoods category, sprouts in these

Table 5. Mean height of the dominant sprout per clump by treatment anc species group.

Treatment	Oaks	Other hardwoods	All hardwoods
	(ft)		
1/10-ac openings			
No understory control	1.1 a[1]	1.8 a	1.4 a
Residuals felled	1.6 a	1.9 a	1.8 a
Residuals felled + herbicide	1.3 a	1.7 a	1.5 a
1/3-ac openings			
No understory control	1.5 a	1.9 a	1.8 a
Residuals felled	2.1 a	2.6 b	2.5 b
Residuals felled + herbicide	1.8 a	2.0 ab	1.8 a

[1] Means within a column followed by the same letter are not signifi- cantly different at the 0.05 level.

treatment areas were significantly taller than for all other treatment co binations (Table 5). Sprouts in these areas originated from small, vig rous trees and were not affected by herbicide application; many were r affected by competition from border trees.

Conclusions

At the end of one growing season, pine-hardwood regeneration appears be successful in small openings which were created to allow a low-quali Piedmont hardwood stand to be managed by group selection. Survival planted loblolly pine seedlings was over 80 percent, and approximately percent of surviving seedlings remained free to grow. Pine mortality du ing the 1st year appeared to be associated with moisture stress rather th from shading or other forms of competition. Even though hardwood regene ation was taller than planted pines, surviving pines doubled in heigh Numerous sprouts and seedlings of oak and other desirable hardwood speci became established in each treatment area.

For pines to continue to survive and grow among hardwood regenerati a balance of hardwood control and available sunlight is needed. The larg 1/3-ac openings provided more sunlight for the moderately intolerant pin but hardwood regeneration overtopped pines where residuals were felled a no herbicide was used. Hardwood vigor was reduced in the smaller 1/10 openings and where residual stems were not felled. However, the increa shading typical of these treatments may prevent rapid pine growth. combination of large openings to provide adequate sunlight and herbicide control hardwood growth may prove most successful for establishing a pi hardwood mixture.

Study plots will be observed for a number of years to evaluate the best mbination of opening size and level of hardwood control. As pine and rdwood regeneration grows, direct competition between species groups will crease. The dynamics of young pine-hardwood mixtures are not well docunted. Recent studies in clearcut areas with similar site quality (medium poor) and aspect (southwest) indicate that pines will survive and over p the hardwood regeneration. However, competition from border trees ineases the difficulty of predicting pine and hardwood survival and growth d requires additional study.

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EFFECTS OF 27 YEARS OF PRESCRIBED FIRE ON AN OAK FOREST AND ITS SOILS IN MIDDLE TENNESSEE [1]

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Abstract. Plots receiving 27 years of annual and 5-year periodic prescribed surface fires were compared to nonburned controls in the oak forests at Highland Rim Forestry Station. Stand overstories were dominated by post oak (Quercus stellata), scarlet oak (Q. coccinea), and southern red oak (Q. falcata), and six other tree taxa. Total tree stem density decreased 21 percent, 47 percent and 48 percent in control, periodic and annual burns, respectively. Basal area increased 36 percent on control plots, increased 14 percent on periodic burn plots, and decreased 5 percent on annual burn plots. Understory stem density decreased 51 to 82 percent among all treatments over the period. Annually burned plots had a grass dominated understory, and 88 percent of the sapling size stems were winged sumac. On control plots soil pH in 1989 was significantly lower than in annual or periodic burn plots. Use of the shrub-grass dominated understory by game animals should be investigated.

Introduction

This paper compares stand conditions following 27 years of annual and periodic prescribed understory surface fires on the vegetation and soils at Highland Rim Forest Station, Franklin County, Tennessee. The study response contributes to our knowledge of soil and oak forest overstory species response behavior to fire and freedom from fire.

The study is at 36° 30′N:86°W at the eastern edge of the Interior Low Plateau Province in middle Tennessee. The land surface here is undulating and has loess derived soils in which a water-movement-inhibiting pan has developed in several series (Fenneman 1938; Fox et al., 1958; Love et al., 1959). Forest vegetation is of the upland oak swamp, post oak-blackjack oak or southern red oak-scarlet oak types (DeSelm et al., 1973). Site index of upland on the Dickson soil common here is 66-75 ft (Moffitt et al., 1972). Conversion of this vegetation to agriculture and to pine plantations is continuing (Thor and Huffman 1969; Buckner et al., 1986).

Early surveyors found a few places with no forest. At such modern sites as the May Prairie, the vegetation has a physiognomic and floristic resemblance to midwestern prairie (DeSelm 1990).

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Thousands of years of native American use (of unknown intensity), ag culture, and livestock grazing between the late 1700s and early 1940s, U.S. Army maneuvers during World War II have been part of this area's h tory. A railroad on the edge of the forest as well as pre-1940 landown formerly were sources of frequent fires (Haywood 1823; Faulkner 1968; Selm et al., 1973).

Methods

Data were collected in nine 1.8-ac rectangular experimental plo three in each treatment (annual fire, periodic fire, and control). N each end of each plot a permanent stake served as a photographic point, overstory and understory tree and shrub sample plot centers. Overst (trees > 5 inches dbh) were sampled using circular 0.2-ac plots. Conc tric 0.01-ac plots were used to sample the woody understory plants 1 tall to 5 inches dbh (Thor and Nichols 1973). At the northern stake each plot, the entire understory was sampled annually using a line-po transect (DeSelm et al., 1973; DeSelm and Clebsch, in press). Annual bu began in 1963; periodic burns were made in 1964, 1969, 1974, 1979, 19 and 1988. Late winter burns were used to simulate the usual time of burn by landowners. Vegetation changes are reported for 1963-1970 and 1970-19

Pre-1989 data are that of Nichols (1971) and Thor and Nichols (197 The 0.2 and 0.01-ac plots were resampled in October 1989. Soils were s pled to a depth of 4 inches at the northern stake of each plot in Aug 1989, and pH and available potassium (K) and phosphorus (P) were determi at the Agricultural Extension Service Soil Test Laboratory, Nashville. number of soil samples taken in each of the measurement years was twelve 1963, six in 1967, eighteen in 1971, and thirty-three in 1989. Samp taken during 1963-1971 were by E. Thor (see Thor and Nichols 1973 for alysis). Taxonomic nomenclature follows Little (1979) or Gleason and Cr quist (1963), who may be consulted for authority.

Results And Discussion

Overstory

Changes in the overstory control plot (Table 1) show an overall crease in stem density during both growth periods. Only scarlet oak (*Qu cus coccinea*) and white oak (*Q. alba*) densities increased. Total ba area increased due largely to increase in scarlet oak basal area. South red oak (*Q. falcata*) basal area decreased (Table 1) while black oak *velutina*) dropped out. Decreases in density with forest development w expected just as was the increase in basal area. Waldrop et al. (19 also noted considerable variation in behavior of individual species c pared with the overall trend. Using basal area as the measure, the cont plots were dominated by post oak and southern red oak in 1963 and 1989 by the latter date developed a closed canopy and well-developed li layer.

le 1. Density and basal area of overstory in 1963, 1970, and 1989 at Highland Forest[1]

cies	Date	Control Density	Control BA	Periodic Density	Periodic BA	Annual Density	Annual BA
		stems/ac	ft²/ac	stems/ac	ft²/ac	stems/ac	ft²/ac
ost oak	1963	56	25.6	47	23.5	60	27.4
uercus stellata	1970	49	27.8	43	23.7	45	27.4
	1989	33	28.0	27	18.7	33	19.3
carlet oak	1963	4	1.3	46	11.3	18	8.9
. coccinea	1970	4	1.6	44	13.6	14	8.9
	1989	30	13.7	14	21.0	8	7.3
outhern red oak	1963	38	17.2	29	14.0	40	16.5
. falcata	1970	32	19.9	34	15.2	36	18.6
	1989	13	16.8	12	14.1	21	22.1
lackjack oak	1963	2	0.9	6	2.0	4	1.6
. marilandica	1970	2	1.0	6	2.0	3	1.4
	1989	0	0	0	0	2	1.0
lack oak	1963	1	0.1	1	0.1	3	0.8
. velutina	1970	1	0.1	1	0.1	3	0.9
	1989	0	0	0	0	2	1.1
illow oak	1963	2	0.3	0	0	0	0
. phellos	1970	2	0.6	0	0	0	0
	1989	0	0	2	1.4	0	0
hite oak	1963	1	1.3	0	0	0	0
. alba	1970	1	1.5	0	0	0	0
	1989	6	5.0	0	0	1	1.5
ed maple	1963	0	0	0	0	0	0
cer rubrum	1970	0	0	0	0	0	0
	1989	0	0	4	2.4	0	0
weetgum	1963	0	0	0	0	0	0
iquidamber	1970	0	0	0	0	0	0
styraciflua	1989	0	0	2	0.5	0	0
Total	1963	104	46.6	129	50.9	125	55.2
	1970	91	52.4	118	54.6	101	54.2
	1989	83	63.5	69	58.1	66	52.3

1963 and 1970 data from Nichols (1973)

The decrease in density (Ca 47 percent) in the periodic burn pl restricted the basal area increase to 7.3 ft^2 (Ca 14 percent). The crease in density occurred despite a small ingrowth of willow oak (*Quer phellos*), red maple (*Acer rubrum*) and sweetgum (*Liquidambar styraciflu* *Blackjack* (*Quercus marilandica*) and black oak disappeared. Basal a dominance in 1963 by post-southern red-scarlet oaks changed by 1989 scarlet-post-southern red oak ranking. The appearance became that of open forest stand with a shrubby understory.

The decline in overall density in the annual burn plots was about percent. Basal area loss was about 5 percent although the scarlet basal area increased about 12 percent. The 1963 post-southern red forest changed by 1989 to a southern red-post oak stand. The appeara was that of an open forest stand with grassy understory.

Assuming linear overstory stem loss rates, the periodic burn pl should be non-forested in 31 more years or by the year 2020. The ann burn plots should be non-forested in 27 years, or by 2016. Use of negat curvilinear estimate would extend the time estimates.

In the periodic and annual burn plots, blackjack, black, white, willow oaks all made small positive or negative density changes. The with the ingrowth of the more fire susceptible red maple and sweet (Langdon 1981) may represent successional changes with impacts on fut composition. The high mortality of post oak and lower mortality of scar oak was also seen by Loomis (1973).

Basal area growth on the plots was 16.9, 7.2 and -2.9 ft^2/ac in c trol, periodic and annual burn plots, respectively. This is +0.63, +0 and -0.11 ft^2/ac/yr compared to 1.74 (control), +1.51 (periodic) and +1 (annual) ft^2/yr growth in the Westvaco pine plots (Waldrop et al., 1987)

Mortality in control plots averaged 0.8, in periodic plots it avera 1.7, and in annual plots it averaged 1.8 percent per year. In the firs years for trees over 6.5 inches dbh in Missouri (Paulsell 1957), these p centages were 1.7, 0.5, and 0.7 percent per year. Scattered control, pe odic and annual burn mortality data for scarlet, black, southern red post oak range from 1.5 to 3.7 percent per year. In the Missouri stu they ranged from 0.8 to 11.4 percent per year.

Droughts are common in middle Tennessee. March through October drou months totaled 97 (30 percent of 328 months) during the period 1929-1 examined by Vaiksnoras and Palmer (1973). During the period 1964-1987 (clusive), 28 percent of the March-October months had precipitation defic totaling 10 percent of the mean for that month. These deficits on droug prone soils with hard pans may partially account for low growth in the c trol plots.

Understory

On control plots, between 1970 and 1989, understory stem density creased from over 8000, to about 1400 stems/ac (Table 2). Only sweet

ble 2. **Density of understory, 1970 and 1989 at Highland Rim Forest.**

ecies	Control 1970[1]	Control 1989	Periodic 1970	Periodic 1989	Annual 1970	Annual 1989
	(stems/ac)					
st oak	1220	20	2000	1033	2400	117
arlet oak	1360	130	2020	550	1980	17
uthern red oak	1510	500	3420	883	3980	50
ackjack oak	20	0	470	83	70	0
ack oak	0	0	0	0	0	50
llow oak	0	100	0	0	0	0
ite oak	0	20	0	223	0	0
d maple	110	80	0	1333	0	0
eetgum	220	350	0	33	0	0
nged sumac	1220	0	2000	1500	1730	2117
ackgum	1530	100	1360	300	1420	0
ckernut hickory	270	30	380	117	400	50
owering dogwood	380	20	0	100	180	0
ssafras	90	0	1400	250	380	0
stern redcedar	0	70	0	0	0	0
rkleberry	130	NM[2]	0	NM	0	NM
erican elm	20	0	0	0	0	0
Total	8080	1420	13050	6415	12540	2401

Data from Thor and Nichols (1973)
Not measured/counted

nsity increased appreciably. Blackjack oak, sassafras (Sassafras albi-m) and American elm (Ulmus americana) disappeared; white and willow oaks d eastern redcedar (Juniperus virginiana) were recruited. These changes present response to protection from pre-1960 railroad and pre-1940 local ndowner-caused fires. Larger stems, free to grow, developed a closed nopy. Gains and losses in species occurrences and density have been also en in secondary succession (Oosting 1942, Smith 1968).

On periodic burn plots, understory stem density also decreased in most ecies. A few species, e.g., red maple, sweetgum, white oak, and dogwood ornus florida), were recruited although the entry of these less fire-apted taxa may be temporary. The invasion of the four above taxa without e loss of other tree taxa occurred despite the presumably hotter periodic res; the gain may be related to the longer interval between fires.

Annual burn plot results indicate great losses in stem numbers for most ecies. Blackgum (Nyssa sylvatica), blackjack oak, dogwood and sassafras sappeared; only black oak was recruited. Winged sumac (Rhus copallina) creased to 88 percent of total density. Although annual fires may be oler than periodic, their frequency of occurrence has resulted in more ecies loss than species gain from invasion.

Soils

Averages of surface soil pH in the various treatments ranged from 4.6 to 5.11. Annual averages for 1963, 1967-1971, and 1989 differed by smal amounts within analytical technique precision and monthly variation (Blac 1965). In 1989, the two burn treatments were not different and average 4.96, while the control averaged 4.72. Increase in pH due to burning (C liberation) has been reported previously (Knighton 1977, Wells 1971).

Treatment averages of surface soil exchangeable K in the above year ranged from 83 to 161 lb/ac. Means between years may be different bu there was no chronological trend. There was no treatment effect.

Treatment averages of surface soil exchangeable P in the above year ranged from 2.0 to 4.0 lb/ac but data were believed to be strongly influ enced by methodology. The samples from 1967 contained the annual burn av erage significantly low 2.0 versus 2.7 and 2.8 in other treatments. Tha year a replicate effect was also seen. There was no overall treatmen effect.

Summary

Overstory stems in control plots decreased 21 percent (to 83 stems/ac and basal area increased 36 percent (to 64 ft²/ac) from 1963 to 198 Three species dropped out, one lost basal area, and two increased in den sity. The stand developed a low, closed forest canopy and a litter layer

Overstory stem density in periodic burn plots decreased 47 percent (t 69 stems/ac) but basal area increased 14 percent (to 58 ft²/ac). Thre species invaded while two dropped out. The basal area of one species (pos oak) decreased.

In annual burn plots the overstory stem density decreased 48 percen (to 66 stems/ac). Basal area also decreased slightly (5 percent to 5 ft²/ac) although the basal area of two species increased. One new specie invaded.

Stem density decreased in the understory of control plots 82 percen (to 1420 stems/ac) since 1970. Four species dropped out. In contrast sweetgum density increased and three other species invaded.

Stem density decreased in the understory of periodic burn plots 51 per cent to 6415 stems/ac. Four new species invaded.

Density of understory stems decreased 81 percent (to 2401 stems/ac with annual burns. Four species dropped out of the plots. Black oa invaded and winged sumac density increased 22 percent--to 2117 stems/ac.

By 1989, pH in the control plots was 0.24 units lower than in burne plots (both treatments). This trend is in keeping with long-term fi effects on soil pH.

The shrub-herb component of the periodic burn plots and the grass mponent of the annual burn plots, along with the great loss in stem nsity and stabilization of basal area in burn treatments support the eory that fire is responsible for the treeless condition of parts of this ea described before, and early in, the settlement period (DeSelm 1990). ese findings suggest that continued burning would result in grassy openngs (prairie, open barren) in the experimental plots by early in the next ntury assuming a linear rate of change.

The productivity of the understory for use by game or domestic animals ould be a topic of investigation to ascertain whether it compensates for e loss in overstory production.

Acknowledgments

These plots are part of the Highland Rim Forestry Station, a facility the University of Tennessee Agricultural Experiment Station and the partment of Forestry, Fisheries and Wildlife. We acknowledge the help of . J. Huffman and M.T. Seay who have managed the plots and took or assisted in data and sample collection. The Tennessee Division of Forestry, anklin County, assisted by Huffman or Seay, conducted the burns. The Dertment of Botany also materially aided the study. Dr. Larry Landers and . Edward Buckner kindly reviewed the manuscript.

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EFFECTS OF PRESCRIBED BURNING AND VARYING BASAL AREAS ON NITROGEN MINERALIZATION IN AN EAST TEXAS PINE FOREST [1]

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Abstract. A cool prescribed burn under different basal areas of natural pine stands in east Texas resulted in no prominent beneficial or deleterious effects on ammonium (NH_4^+) concentrations. Burning did produce a small, but statistically significant increase in nitrate (NO_3^-) concentration. The effects of basal area on nitrogen (N) mineralization were mixed and showed the effects of a forest floor litter volume and microclimate interaction. The possible effects of increased concentrations of NO_3^- after a prescribed burn depend on the density control regime imposed after the burn. Normally little N would be lost following burning in a heavily-stocked stand as the pines would take up some of the newly available N. Hardwood sprouts and new herbaceous vegetation would probably take up substantial amounts of NO_3^-, which would be released as NH_4^+ and taken up by the pines when the other plants decay. Nitrogen released by burning might be conserved in stands to be partially harvested, or harvested and regenerated, by employing stem-only utilization leaving large amounts of organic matter onsite to encourage temporary immobilization of N by wood decaying organisms.

Introduction

The principal forms of inorganic nitrogen (N) found in most soils are ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-), with NH_4^+ and NO_3^- being by far the most common (Bowen and Smith 1981). Mineralization of N can be defined as the transformation of organic, plant-unavailable N into inorganic plant-available forms, primarily through microbial biochemistry (Jansson and Persson 1982). The rates of N mineralization and immobilization are critical to forest nutrition, but the horizontal and vertical variability of detritus makes accurate assessment of net mineralization very difficult (Keeney 1980). Immobilization of mineralized N occurs as heterotrophic organisms utilize any source of inorganic N to further the decomposition of detritus (Tisdale et al. 1985). These heterotrophs can also out-compete nitrifiers for NH_4^+ (Jones and Richards 1977). Since most plants rely entirely on inorganic N, mineralization is a very important process, as are natural and artificial manipulations of factors controlling N mineralization. Two such manipulations commonly used by the silviculturist in managing southern pine stands are prescribed fire and density regulation by basal area. Yet, the effects of these treatments, and interactions between

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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iem, on N mineralization are not fully understood.

Fire is a very powerful environmental factor in the forest (Kimmins 987) and can have major impacts on soil dynamics and plant species. Fire latilizes large amounts of carbon (C), N, and sulfur (S), but also speeds neralization of phosphorus (P), N, and S from the soil organic matter ewis 1974, Vitousek 1981, Holdorf 1982). Inorganic N and P availabilit- s are usually increased after a fire due in part to increased soil pH, mperature, and moisture (Theodorou and Bowen 1983), decreased competition iong plant roots, mycorrhizae, and decomposers for inorganic N, and de- eased immobilization (Raison 1979). The long-term effects of fire on N cles are hard to predict, since they are dependent on the interactions iong soil, plants, climate, fire severity (Raison 1979), and frequency laxwell 1989). But by the destruction of organic material through burn- g, fire can accelerate mineralization and volatilize N to achieve in a w moments what microbial organisms would require years to perform immins 1987).

In contrast to fire, the hypothesized effects of basal area on N min- alization are likely indirect and more subtle. In temperate forests, rvesting generally increases rates of N mineralization, and decreases ant uptake of N (Matson and Vitousek 1981, Vitousek and Matson 1985, tousek and Andariese 1986). Tree spatial distribution irregularities as iall as those opened by single tree removal can affect ecosystem nutrient ows (Vitousek 1985). These areas may exhibit increased nutrient availab- ity due to decreased competition, and increased soil temperature and isture (Vitousek 1985). Mladenoff (1987) found that single tree openings plots dominated by eastern hemlock (Tsuga canadensis (L.) Carr) caused vorable conditions for enhanced microbial activity and increased mineral- ation and nitrification. Thus, manipulations of stand basal area may af- ct the rate of N mineralization through fluctuations in soil temperature d moisture (Vitousek 1981, Theodorou and Bowen 1983, Matson et al. 1987, ison et al. 1987).

The objective of this study is to determine if a mild prescribed burn der natural pine stands in northeast Texas, under different styles or ages of management, as reflected by the range of basal areas, has a aningful impact on N dynamics of these stands. As many stands in this ea have proven to be difficult to successfully regenerate by conventional antation methods, the active pursuit of a dependable method of natural generation has been initiated, as many of these stands were started by tural regeneration.

Materials And Methods

udy Area

The study area is located on land owned by Temple-Inland, Inc., in ierokee County, Texas. The site is positioned 31°41′N, and 95°15′W, with average elevation of 315 ft above mean sea level. The soil is Bowie amy fine sand: a fine-loamy, siliceous, thermic Plinthic Paleudult (Cof- e 1975) that developed under pine forests from acid, moderately sandy rths (Mowery and Oakes 1959). The mean precipitation is 45 inches, dis- ibuted nearly equally throughout the year (Mowery and Oakes 1959). Mean

annual temperature is 66°F, with August being the warmest month (83°F) and January the coldest (48°F) (Mowery and Oakes 1959). The mean annual temperature (collected approximately 6 mi from the site) for the course of the study (11 December 1987-9 December 1988) was 62°F, with the departure from normal distributed nearly evenly during the year. The total annual precipitation for the year (collected approximately 6 mi from the site) was 41 inches. The year-long duration of the study was marked by abnormally dry months, with November contributing 23 percent (9.4 inches) of the yearly total precipitation.

The site is a relatively even-aged upland loblolly- (*Pinus taeda* L.) shortleaf (*P. echinata* Mill.) pine stand with scattered oaks [white (*Quercus alba* L.) and southern red (*Q. falcata* Michx.), post (*Q. stellata* Wangenh.), and bluejack (*Q. incana* Bartr.)], sweetgum (*Liquidambar styraciflua* L.), blackgum (*Nyssa sylvatica* Marsh.), black hickory (*Carya texana* Buckl.) and yaupon (*Ilex vomitoria* Ait.). The site has a site index of 81.4 and 75.6 ft (base age 50 years) for loblolly and shortleaf pine, respectively (Coffee 1975). The stand is naturally regenerated, about 50 years old, and has a mean basal area of 60 ft^2/ac primarily in pine sawtimber 8 inches in diameter at breast height (dbh) and above.

The study was designed to cover basal areas commonly found. Five (replicates)- square 1/1000-ac plots each of 0, 40, and 100 ft^2/ac, simulated natural forest gaps and/or group selection harvests, a shelterwood seed cut for natural regeneration, and mature heavily-stocked stands, respectively.

These study plot basal areas were composed of pine sawtimber 9.6 inches dbh and larger, with no hardwood sawtimber or pulpwood (dbh > 4.6 inches), or pine pulpwood sized trees on the plots, and a minimum of hardwood brush understory. The plots were located with a 10 basal area factor prism.

Each of the 15 1/1000-ac plots was split into two equal subplots, one to be burned and one left non-burned. Soil samples were taken on 9 December 1987, to determine pre-burn NH_4^+ and NO_3^- concentrations. On 10 December 1987, a small boundary was raked around each subplot to be burned, and the litter was ignited using a drip torch. The fire consumed all the OE litter layer on the burned subplot, and extinguished itself when it reached the OA layer, approximately ½ inch above the mineral soil. Soil samples were taken 1 week after the burn to quantify the immediate effects of burning on NH_4^+ and NO_3^- concentrations.

The *in situ* incubation procedures (approximately 1-mo duration) for N mineralization used in this study, called the sequential coring technique, closely follow those of Raison et al. (1987). The advantage of this coring technique is that none of the roots are excluded, but are severed to prevent plant uptake, thus probably yielding a more realistic representation of mineralized N fluxes. Two PVC tubes, approximately 14-16 inches long x 2 inches inside diameter, were driven to a depth of 12 inches on each subplot (burned and nonburned). One tube was left uncovered to allow water to enter for leaching, while the other was covered with a plastic bag and secured with a rubber band to allow gas exchange but exclude water.

This covered tube approach allowed the calculation of net mineraliza-on, excluding most downward movement of soluble N, thus permitting cal-lation of leaching. A soil sample was concurrently collected from a ran-m location outside the cores, in the nonburned subplot. The mineralized in this soil was subject to plant uptake. The rate of plant uptake was lculated by comparing the inorganic N content of this soil to the soil in e cores. Plant uptake in the burned plots was assumed to be the same as the nonburned plots, since the fires were relatively "cool" burns that ly removed the OE litter layer, and likely did not damage the roots im-diately beneath. The soil cores (inside each tube) were left for approx-ately 1 month for *in situ* incubation.

After collection, each soil core was pushed from the tube and divided to three sampling depths of 0-2, 2-4, and 4-8 inches. The soil from each mpling depth, excluding small rocks and large roots was then homogenized. 10-g sample from each sampling depth was mixed with 50 ml of 2 M KCL, and aken on a mechanical shaker, filtered, and analyzed colormetrically for $_4^+$-N, and NO_3^--N with a Scientific Instruments^{tm} continuous flow analyzer. tal inorganic N was calculated by summing the NH_4^+-N and NO_3^--N ncentrations.

The data were analyzed with PC SAS (SAS Institute, Inc. 1985) computer ftware as a nested split-split plot with repeated measures design to de-rmine the effects of varying basal areas and burning on N mineralization. alysis of variance (ANOVA) was used to detect differences between treat-nts. The Student-Newman-Keuls multiple range test was used to test for gnificant differences among treatments and levels of treatments. The 5-rcent probability level was used in all analyses unless noted otherwise.

Results And Discussion

Analysis of the treatment effects revealed replication X burning within sal area, basal area X leaching, depth, and basal area X depth to be the ly significant treatments and treatment interactions for NH_4^+. Replica-on X basal area, replication X burning within basal area, depth, and ba-l area X leaching X depth were the only significant treatments and treat-nt interactions for NO_3^-.

eatment Effects

Burning had no significant effect on NH_4^+ or total mineralized N, but gnificantly increased the soil NO_3^- concentration (Table 1). This effect s been noted elsewhere (Mroz et al. 1980; Covington and Sackett 1986; Ko-cic et al. 1986; Kutiel and Naveh 1987). A hypothesis offered by Coving-n and Sackett (1986) is that increases in NO_3^- after burning may be rtially due to the denaturing of nitrification inhibitors.

The effects of basal area on mineralization were somewhat mixed (Table . The 40- and 100-ft²/ac basal area plots had significantly higher min-alization rates than did the 0 ft²/ac basal area plots. This reflected e fact that although the 0 ft²/ac plots were more exposed, and thus had rsher microclimates, they had significantly less litter layer from which mineralize N.

Table 1. Effect of burning on NH_4^+-N, NO_3^--N, and total mineralized N.

Nitrogen form	Treatment	Conc.	Mass	SNK[1]	Samples
		ppm	lb/ac		No.
NH_4^+ - N	Burned	2.49	5.8	A	761
	Nonburned	2.45	5.7	A	760
NO_3^- - N	Burned	2.27	5.3	A	769
	Nonburned	2.01	4.6	B	768
Total mineralized N	Burned	4.76	11.10	A	769
	Nonburned	4.46	10.30	A	768

[1] Differences among concentrations within N form that are followed by similar letter are not significantly different.

Table 2. Effect of basal area on NH_4^+-N, NO_3^--N, and total mineralized N.

Nitrogen form	Treatment	Conc.	Mass	SNK[1]	Samples
	ft²/ac	ppm	lb/ac		No.
NH_4^+ - N	0	1.98	4.5	A	494
	40	2.82	6.5	B	487
	100	2.60	6.1	B	540
NO_3^- - N	0	1.99	4.6	A	495
	40	2.08	4.8	A	497
	100	2.33	5.4	A	545
Total mineralized N	0	3.97	9.1	B	495
	40	4.90	11.3	A	497
	100	4.93	11.5	A	545

[1] Differences among concentrations within N form that are followed by similar letter are not significantly different.

The NH_4^+ concentrations from the 40 ft²/ac plots were higher, though not significantly so, than the 100 ft²/ac plots. However, the litter layer weights on the 100 ft²/ac plots were significantly greater than those of the 40 ft²/ac plots (Table 3). The higher NH_4^+ concentration on the 40

²/ac plots may illustrate a trend that reflects microenvironmental nditions more conducive to N mineralization, possibly in the forms of gher soil temperatures and soil moisture. The effects of basal area on fferences in NO_3^- concentrations, (Table 2) although not significant, em to be related more to forest floor weight (Table 3), and total tter-layer N concentrations than to microenvironmental conditions, which llows the suggestion of Covington and Sackett (1986).

On the burned plots, NO_3^- concentrations were significantly higher on e 100 ft²/ac basal area plots than on either the 0 or 40 ft²/ac plots able 4). There was no significant difference between NO_3^- levels on the and 40 ft²/ac burned plots.

le 3. Preburn forest floor weights by basal area.

l area	Mass	SNK[1]	Samples
t²/ac	lb/ac		No.
)	286.7	A	15
)	672.4	B	15
)	1211.2	C	15

ifferences among concentrations followed by similar letter are not significantly different.

Table 4. Effects of basal area on NO_3^-– N concentrations in burned plots.

Basal area	Conc.	Mass	SNK[1]	Samples
ft²/ac	ppm	lb/ac		No.
0	2.00	4.6	A	246
40	2.12	4.9	A	233
100	2.60	6.1	B	262

[1] Differences among concentrations followed by similar letter are not significantly different.

One week after burning, there were significant differences in NH_4^+ conntrations under all three basal areas (Table 5). The level of NH_4^+ was ghest on the 100 ft²/ac plots, medium on the 40 ft²/ac plots, and lowest the 0 ft²/ac plots. This is probably directly related to the amount of tter accumulated under these stands prior to burning (Table 3), since rning stimulates NH_4^+ mineralization from organic material. The capture a large flush of inorganic N, primarily as NH_4^+, due to chemical oxidaon of organic matter has been noted in many other studies [Cairns 1963; ssell et al. 1974 (cited in Vance and Henderson 1984); Wells et al. 1978; ison 1979; Pyne 1984; Kovacic et al. 1986; Walker et al. 1986].

e 5. Effects of basal area on NH_4^+– N concentras in burned plots 1 week postburn.

l area	Conc.	Mass	SNK[1]	Samples
²/ac	ppm	lb/ac		No.
0	2.27	5.3	A	18
0	5.66	13.1	B	16
0	8.52	19.8	C	16

fferences among concentrations followed by similar letter are not significantly different.

Table 6. Effects of basal area on NO_3^-– N concentrations in burned plots 1 week postburn.

Basal area	Conc.	Mass	SNK[1]	Samples
ft²/ac	ppm	lb/ac		No.
0	3.70	8.6	A	18
40	2.82	2.5	B	16
100	1.55	1.4	C	16

[1] Differences among concentrations followed by similar letter are not significantly different.

The effects of basal area on NO_3^- concentrations 1 week after burning were somewhat surprising, with NO_3^- levels increasing as basal area decreased (Table 6). This effect has been seen elsewhere and has been attributed to denaturing of nitrification inhibitors (Covington and Sackett 1986). A hypothesis regarding the increase in NO_3^- concentrations with decreasing basal area, is that the litter layer quality was different among the different basal areas. That is, the proportion of grasses and herbaceous litter to pine needle volume would decrease with basal area. This non-needle fraction would be much more easily decomposed than the needle fraction due to much lower C:N ratios, and lignin contents. The presence of this higher quality, non-needle litter may have stimulated nitrification.

Ammonium and Nitrate Correlations

An examination of correlation coefficients for NH_4^+ and NO_3^- (Table 7), and associated significances, reveal a few interesting points that support work by others. Nitrate concentrations were shown to be less affected by depth than NH_4^+, although both were negatively correlated ($p < 0.001$) with depth. A possible explanation for this is that NO_3^- is a much more mobile element in solution than NH_4^+, which is suggested by the differences in correlation between NH_4^+ and NO_3^- with total rain ($p < 0.001$). Also NH_4^+ is correlated ($p < 0.001$) with mean temperature and soil moisture percentage, while NO_3^- is not significantly correlated with either. Examination of these correlations seems to indicate that NO_3^- is more dependent on the amount of NH_4^+ available for nitrification than on environmental constraints.

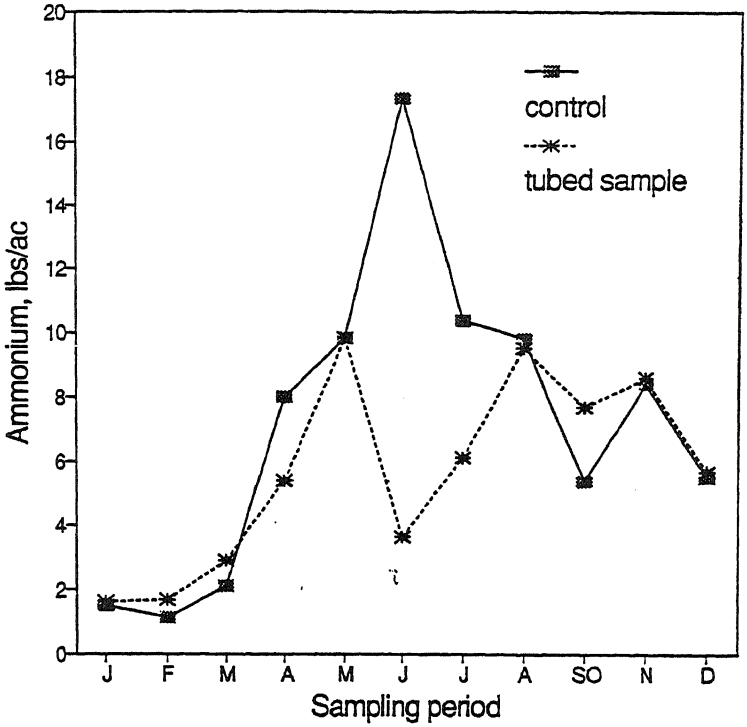
Table 7. Correlation coefficients for NH_4^+-N and NO_3^--N.

Factor	NH_4^+ - N	NO_3^- - N
NO_3^- - N	0.05813*	---
Month	0.28060***	-0.24109***
Basal area	0.08527***	0.05469*
Depth	-0.30148***	-0.17103***
Total monthly rainfall	-0.10188***	-0.12502***
Mean monthly temperature	0.30151***	-0.00981
Percent moisture content	-0.12985***	-0.01109
Bulk density	-0.28332***	-0.09976***

* P< 0.05
** P< 0.01
*** P< 0.001

Immobilization

The mixed results of NH_4^+ in the control and tubed samples (Fig. 1) suggests greater immobilization in the tubed samples over the control



gure 1. Ammonium concentration in control versus tubed samples. Signif-ant differences between control and tubed samples occurred in April and ne sampling periods, differences in all other sampling periods not gnificant.

mples during the hottest summer months when decomposition was assumed to most rapid. Immobilization is thought to be the reason that the tubed mples did not show higher concentrations of NH_4^+ than the control samples r most of the duration of this study (Fig. 1).

The months during which the tubed samples had higher NH_4^+ concentra-ons than control samples may have been months in which fine root decompo-tion and possible increased immobilization did not occur because of vironmental factors. Raison et al. (1987) suggested this possibility and ated that the effects of root severing and subsequent possible N immobil-ation from the decaying roots needed to be minimized. This is also sup-rted by Poovarodom et al. (1988) and Adams et al. (1989) who observed at the presence of dead roots in an undisturbed soil sample would act as large source of C and would probably stimulate N immobilization. Adams al. (1989) also argue that all of the methods commonly used to study N neralization alter the environment inside the tubes by: (1) elimination C input from decomposing forest-floor litter and fine-root turnover; (2) creased C inputs from newly severed roots; (3) modification of moisture d temperature regimes; and (4) accumulation of inorganic N by prevention plant uptake.

Our in situ methodology probably did not seriously affect N mineralization from the standpoints of moisture and temperature modification. However, we suspect that increased C inputs from roots severed by tube installation, which would result in increased microbial immobilization, was a factor in our results. Apparently, the length of in situ incubation of a soil with newly severed roots has a direct effect on the mineralization-immobilization processes. Shortening the duration of incubation would minimize the effects of immobilization in areas and/or seasons of rapid decomposition and also minimize underestimation of both net N mineralization and plant uptake. Poovarodom et al. (1988) found large variations in the rates of mineralization, as was the case in this experiment. Noting similar variations in the work of others (Pastor et al. 1984; Harmer and Alexander 1985), they concluded that this would possibly be the norm for this type of research.

Conclusions

A cool prescribed burn on the study site had no distinct beneficial or deleterious effects on NH_4^+ concentrations during the study. The burn did produce a small significant increase in NO_3^- concentration. The fact that NO_3^- concentrations were increased while NH_4^+ was not suggests that while burning did not increase the average pool size of NH_4^+ at any particular time, it did increase the amount and rate of NH_4^+ cycling through the system, some of which was nitrified. The net effect of this increase in rate of NH_4^+ cycling is: (1) an actual increase in the rate of mineralization; (2) an increase in the rate of nitrification; and (3) an increase in the concentration of NO_3^- in the soil. The effects of basal area on N mineralization were mixed and show the effects of a forest floor litter volume and microclimate interaction. The NH_4^+ concentrations by basal area (Table 2) show the effects of the forest floor as a source of N for NH_4^+ mineralization by the 100 and 40 ft²/ac plots having significantly higher NH_4^+ concentrations than the 0 ft²/ac plots. The fact that the 40 ft²/ac plots had slightly higher NH_4^+ concentrations than the 100 ft²/ac plots may be due to increased exposure to soil water and temperature fluctuations on the 40 ft²/ac plots. Also the lower immobilization than on the 100 ft²/ac plots may be due to less root mass in the soil. The effects of basal area on NO_3^- concentrations (Table 2) show nitrification to be more dependent on NH_4^+ availability, as expressed by increasing forest floor mass with basal area (Table 3), than on microenvironment in this stand.

The possible effects of increased concentrations of NO_3^- after a prescribed burn vary according to what management activities follow the burn. Natural pine regeneration that became established in stand openings, such as those represented by the 0 ft²/ac plots, would probably compete with other pioneer forest plants for light, water, nutrients, and growing space. As long as the pine was not overtopped by competing vegetation, the other plants could serve as a nutrient "bank" to hold the additional NO_3^- until their death. This effect would probably not be notable if there were only a few gaps, or if the gaps were very scattered. If however, the gaps were close and/or numerous, this effect could result in a considerable amount of NO_3^- being in circulation on the site at one time. As such, conservation of NO_3^- may be accomplished by using a low- intensity stem-only harvest just prior to seedfall.

The 40 ft²/ac plots simulate the maximum basal area left after a shel-rwood seed cut. There would probably be a considerable amount of NO_3^- in rculation in this situation. One could expect more competition to new edlings than before harvest, because of more light reaching the ground, ereby stimulating revegetation. A stand such as this would probably be rned, then harvested just prior to seedfall. The burn would remove some the litter layer to expose a seedbed and also temporarily reduce hard-od competition. The harvest just before seedfall could maximize seedling tablishment by providing maximum scarification of the seedbed before it uld be covered by leaves or vegetation. A low-intensity, stem-only har-st again could aid in conserving NO_3^- by leaving woody organic material site to help immobilize some NH_4^+, thus indirectly minimizing nitrifi-tion. This scheme could also aid in site regeneration by cones in log-ng slash dropping seed also on site.

The 100 ft²/ac plots represent heavily stocked stands which would like- be thinned soon. It is quite probable that these stands would be pre-ribed burned prior to harvest to facilitate cruising, marking, and rvesting, as well to reduce the risk of wildfire before harvesting sidue is added to the litter already on the site.

This study suggests that when a heavily-stocked pine stand in northeast xas is prescribed burned, NO_3^- production will be at a maximum compared those that are being prepared for natural regeneration, or group selec-on management. This NO_3^- would likely not be lost to leaching. The nes would probably take up some of the newly-available NO_3^-. Hardwood routs and herbaceous undergrowth that came in after the fire would prob-ly take up a substantial amount of the NO_3^- also. The uptake by these ants could also indirectly benefit the pines, since when these plants entually decompose the N they removed from the soil as NO_3^- would be turned as NH_4^+, which the mature pines probably prefer.

Acknowledgments

The authors gratefully acknowledge the assistance of Temple Inland Cor-ration, Diboll, Texas, who made land available and financially supported is research. This research was conducted when the senior author was a aduate research assistant in the Department of Forest Science, Texas A&M iversity, College Station.

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THE FIRST LOCATION OF A NATIONAL, LONG-TERM FOREST SOIL PRODUCTIVITY STUDY: METHODS OF COMPACTION AND RESIDUE REMOVAL [1]

Allan E. Tiarks, Melinda S. Kimble, and Michael L. Elliott-Smith [2]

Abstract. To ensure that Forest Service management practices do not reduce long-term soil productivity, a network of coordinated, long-term experiments is being established across the United States. This national study plan calls for three levels of compaction (none, moderate, and severe) and three levels of organic matter removal (bole only, total tree, and total aboveground biomass). In this paper, the establishment of the first of these installations in central Louisiana is discussed. A loader was used to reach in and lift logs off the uncompacted plots instead of equipment entering the plots during harvest. Moderately compacted plots were rolled by a pneumatic-tired compactor loaded to 2.34 Mg/m, while a 4.22 Mg/m load was used for the severely compacted plots. After treatment, the bulk densities at the 0- to 10-cm depth were 1.47, 1.54, and 1.60 g/cm^3 for the none, moderate, and severe levels, respectively. The densities at the 10- to 20-cm depth were 1.61, 1.63, and 1.69 g/cm^3, while the treatments had no effect at the 20-30 cm depth. Of the 98 Mg/ha aboveground biomass on the plots, the bole-only removal left 23 percent of the biomass while the total tree harvest left 6 percent. Biomass contained about 155, 17, 63, 100, and 25 kg/ha of nitrogen, phosphorus, potassium, calcium, and magnesium, respectively. The concentration of nutrients was higher in the foliage and understory components of the stand, so proportionately more nutrients were removed as the harvest intensity increased.

Introduction

Harvesting forests may lower ong-term productivity on Coastal lain soils that are commonly fraile and easily degraded. In the outh, much of the present pine forst was cropland at some point in the last century. A decline in annual production during the previous agricultural phase demonstrated the fragility of the soils. Reduced crop yields, caused by erosion, low fertility, soil compaction, and low water-holding capacity, led to abandonment and eventual reforestation of these fields. The effects of forest management on soil productivity are less apparent because harvests are made in cycles of decades, not years. The degree of productivity loss will be related to the cumulative amount of equipment entering a stand and biomass

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Paper presented at Sixth Biennial outhern Silvicultural Research Conerence, Memphis, TN, Oct. 30-Nov. , 1990.

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removed, so a reduction may occur in any silvicultural system regardless o the type of management. Since the effects of management practices on soi productivity may not be obvious to land managers, formal, long-term mon itoring and research studies are needed to develop proper managemen practices.

Legislation

Recognizing the insidious nature of the loss of soil productivity i public forests, Congress passed the National Forest Management Act of 1976 This law charges the Secretary of Agriculture with ensuring research an monitoring the effects of each management system to protect the permanen productivity of the land (USDA Forest Service 1983). The ensuing Code o Federal Regulations for Forest Planning requires the Forest Service to mon itor the effects of prescriptions, including "significant changes in lan productivity" (U.S. Code of Federal Regulations 1985). Soil quality mon itoring is seen as a three-stage process whose first two stages, implemen tation and effectiveness monitoring, depend on professional judgment (USD Forest Service 1987). The final stage, validation monitoring, depends o research results of measurable soil variables that are linked to soil pro ductivity (Powers 1990). Of the many soil variables that may be affecte by forest management practices, soil porosity and organic matter conten seem to be the most important (Powers et al., 1990).

Soil Variables

Soil porosity, at a given particle density, is proportional to the bul density. Although total soil porosities are important, pine root growth infiltration, internal drainage, and other factors affecting long-term productivity are more closely related to the pore distribution (Soane 1990) Soil compaction by heavy equipment used for logging and site preparatio can severely reduce macropore space, especially in the surface horizon. The amount of organic residue left on the surface can also influence th porosity of the soil. Organic residues protect the soil surface from raindrop impact, provide food and cover for burrowing soil animals, and increase soil aggregation.

Other Factors

Intensive harvest and site preparation practices that remove more tha the bole can also affect the long-term productivity of the site by influencing the amount of nutrients available to the next rotation. The concentration of nutrients in the woody stem is much lower than in the othe tree parts. For instance, in a 35-year-old loblolly pine (*Pinus taeda* L.), stems contain 72 percent of the aboveground organic matter, but only 22 percent of aboveground nitrogen and 32 percent of the phosphorus (Switzer and Shelton 1984). The trees contain only 2 to 12 percent of the nutrients in the system (Switzer and Shelton 1984), with the remainder in the soil. However, in Coastal Plain soils, the trees may contain as much as one-third of the phosphorus on the site (Wells and Jorgensen 1979). Thus, the amount of forest residue removed from a site will affect long-term soil productivity because much of the nutrient requirement is cycled through the aboveground biomass (Switzer and Nelson 1972).

il Productivity Study

For these reasons, Powers et al. (1990) proposed that a national, long-rm soil productivity study be initiated with treatments that manipulate il porosities and organic residues spanning the range of environmental resses possible under present or future management. This series of ress experiments will develop the fundamental relationships between site sturbances, growth processes, and long-term productivity. The results ll permit implementation of monitoring standards related to productivity a solid, scientific basis. Study sites are to be located in all major mber types in the country, including 13 sites of loblolly pine on the astal Plain (Powers et al., 1989).

In this paper, the first installation of the national study on a lob-lly pine site and the protocols of imposing the treatments are described. velopment of standard protocols is necessary to ensure that sites pres-tly being installed in California, Idaho, Louisiana, Minnesota, and North rolina, as well as future locations, can be compared. The results also st the range of stress applied. As in any study, the validity of the in-rpretations will be greatest if the treatment levels are at the minimum, ximum, and midpoint of the range.

Methods

cation

The installation was located in a loblolly pine stand selected on the sis of typical stand structure, past management, and common soil series. e plots are on the Longleaf Tract of the Palustris Experimental Forest in e northwest quarter of the southwest quarter of section 26, T1N R3W in pides Parish. The study site is on rolling terrain of Malbis and Beau-gard soils. The plots are on uniform 3 to 7 percent slopes (Malbis soil) d are surrounded by Beauregard soils on the ridge tops and Caddo soils ong the lower slopes. Site index for loblolly pine on Malbis is 90 at se age 50 (Kerr et al., 1980).

scription of Preharvest Stand

The harvested stand was established as a direct seeded study in 1953. itial survival was 2,500 seedlings/ha, but drought and competition from ender bluestem reduced this number to 1,032 seedlings/ha at the end of e second growing season. During mid- to late rotation, the stand had en thinned as part of normal management. The stand is in a range man-ement area that has been grazed at a moderate stocking over the last cade. Winter prescribed burns were done on a 3- to 5-year cycle with the st 1 year before harvest.

After the plots for the present study were located, the pines and un-rstory were measured and sampled. The diameter at breast height (dbh) of l live pines (dbh > 7.5 cm) was measured. The height of every tenth tree s measured with a clinometer. The height of the trees ranged from 12.2 27.1 m and averaged 20.5 m (Table 1). Average dbh was 30.3 cm, and nged from 8.6 to 52.8 cm. The average density of trees was 226/ha.

Table 1. Number of trees, height, and dbh per plot before harvest.

Compaction level	Organic matter removal	Density	Height	Dbh
		(trees/ha)	(m)	(cm)
None	Bole only	192	21.9	32.2
	Total tree	246	20.1	29.8
	Total aboveground	173	20.4	31.3
Moderate	Bole only	272	20.1	29.2
	Total tree	199	20.2	29.5
	Total aboveground	232	20.2	30.5
Severe	Bole only	213	20.1	29.1
	Total tree	267	20.9	29.9
	Total aboveground	239	20.3	31.4
Mean		226	20.5	30.3

From this information, three sample trees were selected by stratifi random sampling to represent a cross-section of each plot. The trees we felled and disks were taken every 2 m for stem and nutrient analyses. A bark from these disks was dried, ground, and mixed to get a composite sa ple for each tree. A 30-degree sector of the wood in each disk was treat in the same way so that the material in the samples was proportional to t total in the tree (Auchmoody and Greweling 1979). Branch and foliage sa ples were also taken from these trees. Total biomass of the pines was ca culated using equations for dry weights (Baldwin 1987).

Combined herbaceous, litter, and forest floor samples were collect using a randomly-placed, square frame (0.47 x 0.47 m). Ten samples p plot were clipped, bagged, dried, weighed, and saved for nutrient analyse Attempts to separate the litter and forest floor from grasses and oth herbaceous materials proved to be hopeless. Brush cover was estimated the line intersection method (six lines per plot) with random samples tak for nutrient analysis. The mass per unit area of brush was estimated fr the weight of the litter and herbaceous sample by assuming an equal weig per unit of ground cover. The litter, herbaceous, forest floor, and bru components were summed to obtain biomass and nutrient values for the unde story component.

Soil Measurements

Before plots were established, four transects were made 100-m apa with simple descriptions recorded every 20 m along each transect. Th information was used to locate plots on uniform soils. A hand-coring a paratus (Ruark 1985) was used to take bulk density samples from the 0 to 1 cm depth at random locations on each plot before harvest. The variabili found from this sampling indicated that seven samples are required for th

asured bulk density to be within a range of 0.05 g/cm^3 at 90 percent obability. Ten samples were collected after application of the compacon treatments at the 0 to 10, 10 to 20, and 20 to 30 cm depths.

perimental Design

The national "generic" study plan (Powers et al., 1989) calls for a re installation of nine treatments consisting of a factorial of the folwing three levels of organic matter removal and soil compaction. Organic tter removal consisted of: (1) boles only removed; (2) total tree remov; and (3) total aboveground biomass removed. Soil compaction was: (1) no mpaction; (2) moderate compaction; and (3) severe compaction. Each plot split into a subplot receiving no herbicide and a subplot from which all n-pine vegetation will be removed by herbicides. Normal management pracces are being applied to a 10th plot. None of the treatments is replited, but this location is along the productivity gradient specified in e national plan. The data from all locations will be combined and anazed using regression models.

The plots receiving moderate or severe levels of compaction are 65 x 65 A 10-m-wide access strip for logging was placed in the middle of the compacted plots so they are 65 x 75 m in size. Within each vegetation ntrol subplot, there is a 20 x 50 m measurement plot. There are 160 nes planted in each measurement plot at a 2.5 x 2.5 m spacing.

gging of Plots

The plots that were to be compacted were logged with a grapple skidder; gs were removed from the uncompacted plots by lifting them with a loader. ees were delimbed before they were removed from plots designated bolely removal; on the other plots the trees were delimbed after removal from e plots. The small amount of nonmerchantable material was treated like e limbs for the plot. The logging was done in November and December 1989 en soil moisture levels were low.

mpaction of Plots

A pneumatic-tired roller was towed by a farm tractor or small crawler compact the plots. The machine is a metal box mounted on a front axle six wheels and a rear axle of seven wheels, for a total rolling width of 13 m. The rear axle is offset by one tire width so the machine covers 0 percent of the surface. Inflation pressure of the 7.50 by 15 tires was intained at 310 kilopascal (kpa). Sandbags filled to a known weight were ed to adjust the ballast. In studies where flexible tires pass over ils with moderate bearing capacity, both the soil and the tire charactertics determine ground pressure in a complex way (Hakansson et al., 1988). a forest, the presence of roots, stumps, and large animal burrows adds the complexity. Since ground pressures are indeterminable, the loads e expressed as mass per unit of summed tire widths with the units of gagrams per meter (Mg/m). Before compaction of the plots, the weight of llast plus machine required to initiate compaction was determined by ial and error to be 3 Mg, or 1.4 Mg/m. The load for the severely-compcted plots was preset at 9 Mg (4.2 Mg/m), as heavier loads increase the pth of compaction but not the degree at the surface (Voorhees et al., 78). The load for the intermediate level was set as the logarithmic erage between these two points (2.3 Mg/m).

After the ballast was loaded, three passes were made over each ar one direction, followed by three passes in a perpendicular direction, total of six passes over all areas on the plots. The machine was towe er short stumps and around larger ones. On bole-only removal plots pine limbs were pulled aside, the area compacted, and the limbs rep and evenly distributed.

Planting

Seed from 10 half-sib families from Forest Service seed orchar Louisiana and Mississippi were used to grow containerized seedlings. families were selected for their ability to perform well in existing eny tests. The seed was stratified and planted in containers in the s of 1989, with the families separated and identified. Planting of the commenced on February 14 and was finished by March 14, 1990. The fam were randomly planted in each plot, but 16 trees from each family planted in each measurement plot, and the genetic identity of each tre recorded. The same containerized material was used to plant the b rows. Seedlings killed by Pales weevil and unknown causes were replac March 26, 27, and again on April 12 with seedlings from the same famil

Cultural Treatments

All seedlings on the plots were sprayed with Dursban™ 3E on Mar and 27, 1990. The insecticide was effective in control of the Pales il, and no additional insect damage was noted the 1st year. On ha each plot, competing vegetation will be controlled so that treatmen fects on maximum productivity can be measured. A broad spectrum of bicides will be used to control all competing vegetation until pine c closure, or about age 5. For control in the 1st year, Oust™ was sp at the rate of 0.42 kg/ha on June 1, 1990.

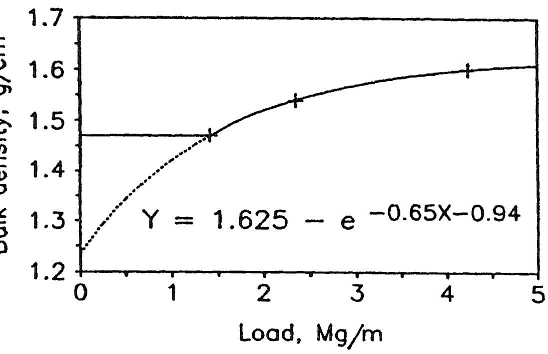
Normal Management Plots

To evaluate the effects of present standard or normal management tices, a control plot was established after the logging operation area that appeared to have been logged in a manner typical for the re This plot was planted at the same time and with the same seedlings a other plots. Half of this plot will be managed using present pract The other half will be treated the same, except that 50 kg/ha of phosp fertilizer will be applied at the beginning of the fourth growing se The delayed application is based on research at the experimental f showing that phosphorus fertilizer is most effective if applied afte pines shade the grass competition.

Weather Station

A recording weather station was located at this installation and be located at all future installations for two reasons. First, becaus plots are being installed at different geographical locations in diff years, the weather stations will be used to account for differences in mate. Second, the data will be used in process modeling of the veget development. The station was placed in an open area at least 30 m fro nearest plot to minimize changes caused by the growing stand. Cli parameters measured include air and soil temperatures, wind speed and rection, rainfall, humidity, total solar radiation, photosynthetically tive radiation, and soil water tension. Readings are made every 5 min

t only the hourly averages are recorded. The data are maintained on com-
ter disk for easy manipulation. Recording commenced on February 23,
90.



gure 1. Effect of the different mpactor loads on the bulk density the 0 to 10 cm depth.

Results

Soil Bulk Densities

By trial and error in the field, an approximate relationship between applied load and bulk density was developed (Fig. 1) using an exponential curve (Larsen et al., 1980). The intersection of the curve with the Y axis indicates that the bulk density of this soil would be approximately 1.22 g/cm³ in a normal state. However, past management, including grazing (Linnartz et al., 1966), compacted the surface to 1.47 g/cm³, so loads up to 1.4 Mg/m were not sufficient to cause nonrecoverable compaction (Gill and Vanden Berg 1967). The load on the compactor was adjusted so the bulk density of the 0 to 10 layer of soil increased to 1.60 g/cm³ for the severe level (Table 2, g. 1). The target density for the severe level was 1.61 g/cm³, which is percent of the difference between the growth-limiting density (Daddow d Warington 1983) and the original state. In the 0 to 10 cm layer, the lk density of the moderately compacted plots was midway between the nsities in the other two treatments.

The moderate level of compaction had little effect on the bulk density the soil at the 10 to 20 cm depth, but the severe level increased the nsity from 1.61 to 1.69 g/cm³. The compaction treatments had no effect the bulk density of the soil at the 20 to 30 cm depth.

The effect of the compaction treatments on the distributions of bulk nsities in the plots is shown in Figure 2. Even without additional comction, densities ranged up to 1.65 g/cm³. The compaction treatments elinated any samples less than 1.40 g/cm³ and increased the range up to 80 g/cm³. Comparison of the distribution of densities on the different eatments indicates that the roller increased the bulk density without anging the standard error of the means (Table 2), showing that the entire ot was compacted uniformly and realistically.

omass And Nutrients Removed

The largest amount of biomass was in the boles of the pines harvested, th 78 percent of the dry weight in this component, which was removed by e bole-only removal treatment (Fig. 3). Another 17 percent of the total omass was removed in the total tree removal, and only an additional 5 rcent was removed in the total aboveground removal treatment. These numrs are the averages for the nine plots, not just the plots that received e targeted treatment. Individual plots were as much as 19 percent below

to 21 percent above the means. The amount of nutrients in the stand rang from 155 kg/ha for nitrogen to 17 kg/ha for phosphorus. As expected, tl relative amount of nutrients removed was evenly distributed among tl treatments even though most of the biomass was removed by the bole-onl treatment (Fig. 3).

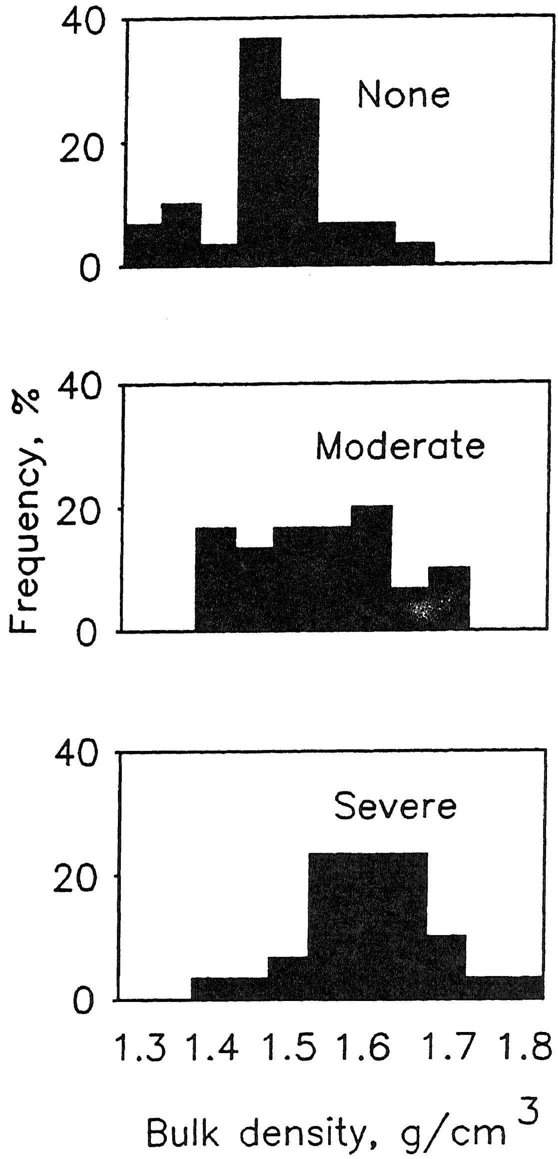


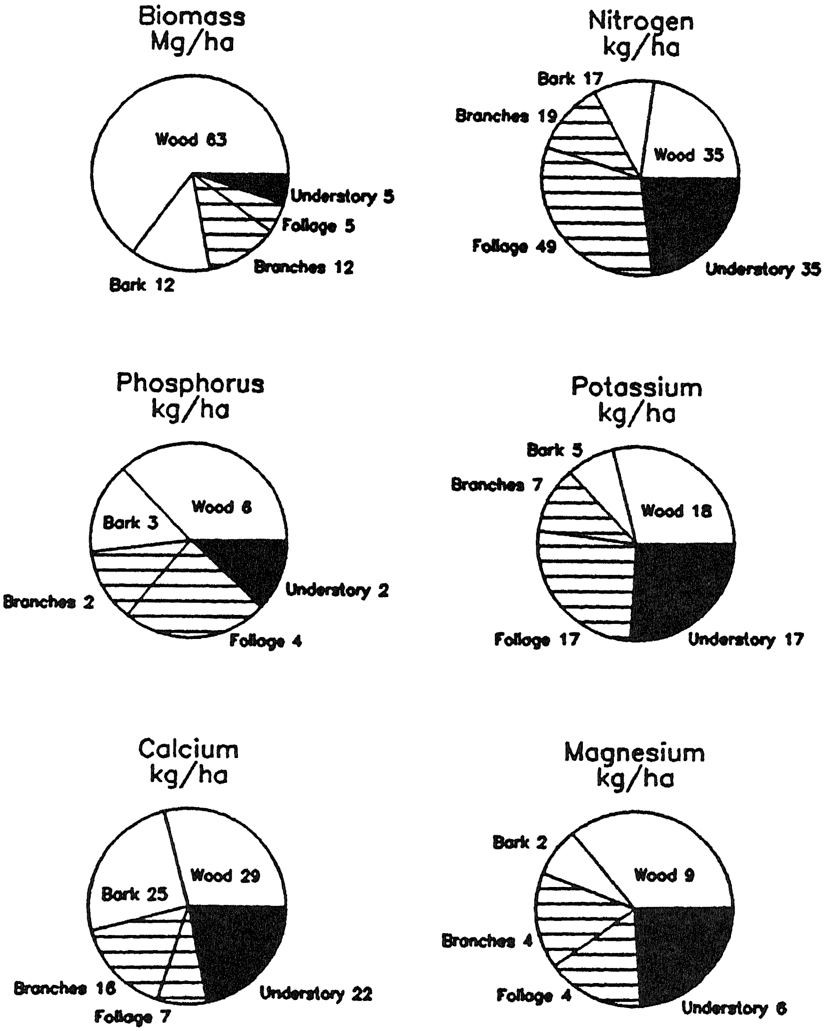
Figure 2. Distribution of bulk densities measured in the 0 to 10 cm depth after application of the compaction treatments.

Discussion And Conclusions

The initial bulk density of th surface soil was higher than expec ted, probably as a result of graz ing (Linnartz et al., 1966). How ever, it was still possible t impose a range of bulk densitie that should affect pine growth. A shown in Figure 2, the variabilit in bulk densities is about the sam for the soil in the uncompacted an severely compacted plots, so th roller compacted the soil in an ac ceptably uniform and realistic man ner. While more than three quar ters of biomass on the site wa removed by the bole-only treatment about one-third of the nutrien capital was in the crowns and an other quarter was in the understor (Fig. 3). Thus, in terms of qual ity of organic matter returned t the soil, the treatments imposed a acceptable range.

The plots will be maintaine and measured throughout the 60-yea rotation. During that time, th growth of the pines and other vege tation will be closely monitore for any changes in productivity Soil and plant samples will be tak en periodically to measure change in nutrient availablity associate with the treatments. According t a regime to be developed based o basal area, the stand will be thin ned later. Soil physical proper ties will be measured to follow th recovery of the soil after the com paction treatments. These measure ments will include repeated bull density samplings, penetrometer re sistances, soil temperatures, an infiltration measurements.

It is hoped that other scientists will be able to use these plots to easure the effects of logging on the soil fauna and flora, especially as ie network of plots is expanded across the country. The network of in-:allations will be used to study the fundamental processes and relation-iips among tree growth and soil properties, organic residues, and climate. odels will be developed for use in the monitoring process so that the man-;ement of public forests will rest on a scientific foundation.



gure 3. Relative amounts of biomass and nutrients of the different com-nents of harvested stand. Open sectors are bole-only harvest; open plus tched sectors represent the total tree harvest; and the complete pie is e aboveground material. Understory includes brush, grasses, herbs, lit-r, and forest floor. The numbers are the actual weights in each mponent.

Table 2. Average bulk densities of the soils after compaction at three depths over the three residue removal treatments and probability of treatment differences occurring by chance.

Sample depth	Compaction treatment			Probability
	None	Medium	Severe	
(cm)	(g/cm³)			
0-10	1.47 (0.02)*	1.54 (0.01)	1.60 (0.02)	0.0001
10-20	1.61 (0.02)	1.63 (0.02)	1.69 (0.01)	0.0005
20-30	1.56 (0.01)	1.55 (0.02)	1.57 (0.01)	0.398

* Standard error of the means are shown in parentheses.

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MODELING BULK DENSITY, MACROPOROSITY, AND MICROPOROSITY WITH THE DEPTH OF SKIDDER RUTS FOR A LOESS SOIL IN NORTH-CENTRAL MISSISSIPPI [1]

Bob L. Karr, James M. Rachal, and Yanfei Guo [2]

Abstract. Bulk Density, macroporosity, and microporosity of a loess soil (Memphis silt loam) in north-central Mississippi were regressed with four depths of skidder ruts by slope position. Bulk density increased exponentially as a function of rut depth, with r^2 values as high as 0.71 for the 0- to 7.6-cm soil depth on the upper slope. Macroporosity decreased exponentially as a function of rut depth, with r^2 values as high as 0.83 for the 0- to 7.6-cm soil depth on the upper slope. Models for bulk density and macroporosity at 7.6-15.2 and 15.2-22.9 cm depths at upper- and midslope positions were more linear and did not account for as much of the variation as did those for the 0- to 7.6-cm depth. Regressions of microporosity with depth of ruts were not significant.

Introduction

Equipment may traverse a large part of the forest floor during a harvest. Karr et al. (1987) reported that areal disturbance occurred on 28 to 47 percent of the area in the thinning of a loblolly pine (Pinus taeda L) plantation. However, the number of passes and the amount of disturbance by the skidder varies among trails (Campbell et al. 1973). Leaving the log deck via a primary skid trail to obtain another load of logs, the skidder operator may exit to a secondary trail that branches into a network of higher order trails. The return trip of the loaded skidder leads the skidder back to the primary trail and the log deck. The result is greater use and disturbance of the lower order trails than that of the higher order trails.

The weight of the skidder and logs compacts and frequently displaces the soil, forming a rut. However, the extent of the disturbance depends primarily on the number of passes by the skidder and the amount of soil moisture. It has been shown that 60 percent or more of the increase in bulk density of a soil occurs within 3 or 4 passes of the skidder (Guo and Karr 1988). As soil moisture increases, the load-bearing strength of the soil decreases and the tires of the skidder break through the soil surface creating a rut. Although foresters can do little to manage soil moisture, they can do much to prevent the rutting of soils by scheduling logging when soils are dry.

The relationship between rut development and the increase in soil

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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bulk density, or the decrease in porosity, needs to be studied. We kn that as soil moisture increases soil strength decreases, and rutting occu more readily. However, does a rut 10-cm deep alter bulk density twice much as that of a 5-cm rut? Our objective was to determine the effect th the depth of skidder ruts have on soil bulk density and porosity.

Methods

We located a loblolly pine stand in north-central Mississippi that w being harvested. The site consisted of 15 to 20 percent slopes dominat by Memphis silt loam (fine-silty, mixed, thermic Typic Hapludalfs). T slopes were stratified into upper, middle, and lower slopes for samplin and originally classified ruts by depth into six classes: class 1 = u disturbed; class 2 = 0.0-3.8 cm; class 3 = 3.8-7.6 cm; class 4 = 7.6-8 cm; class 5 = 8.9-12.7 cm; and class 6 = > 15.2 cm. However, rut classes and 6 occurred so infrequently that they were included with class 4.

At five locations we removed undisturbed soil cores at depths of 0-7. 7.6-15.2, 15.2-22.9 cm for each rut class present, for a total of 159 sam les, to determine soil bulk density and porosity. All rut classes did n occur at every location. The laboratory procedure for determining bu density, total porosity, microporosity, and macroporosity followed that Cassel (1974). The procedure used filter funnels with fritted discs which the saturated soil cores were placed. We siphoned water that drain from the soil cores before applying pressure. This volume represents t volume of super macropores. Next, we sealed the top of the funnels, a plied 0.006 MPa of pressure for 12 hours, collected the water that was fo ced through the fritted disc, and added its volume to that of the sup macropore to determine macroporosity. Soils were dried for 72 hours 105°C and loss of water determined. This water loss expressed as a perce of total volume represents the percent of micropores. The percent of mi ropores summed with that of macropores equals total porosity. The weig of the dry soil core divided by its volume is the bulk density (g cm^{-3}) the soil core.

Microporosity was regressed with depth of ruts, but all models were i significant at $p = 0.05$ level of probability. Consequently, models pr sented will be for bulk density and macroporosity.

Ruts on lower slope positions contained soil that was eroded from upp slope. Samples were taken in these deposits and were not representative the soil at the base of the ruts. Consequently, lower slope position w not included in the models.

Scatter diagrams and regression analysis performed with SAS (1988) de onstrated that an exponential or an exponential polynomial model best fi ted the data for bulk density and macroporosity at each of the three dept for both the upper and mid-slope positions. The models were:

$$Y = be^{mx} \qquad [1]$$

$$Y = be^{mx+nx^2}, \qquad [2]$$

Where: Y = soil bulk density or macroporosity;
x = rut class, and;
b, m, n = coefficients.

Transformation by the natural logarithm converted models one and two for the following regression analysis:

Equation 1

$$\ln(Y) = \ln(b) + mx\{\ln(e)\} \qquad [3]$$

since $\ln(e) = 1$,

$$\ln(Y) = \ln(b) + mx$$

Equation 2

$$\ln(Y) = \ln(b) + (mx + nx^2)\{\ln(e)\} \qquad [4]$$

or,

$$\ln(Y) = \ln(b) + mx + nx^2. \qquad [5]$$

Results And Discussion

Bulk Density

Rutting increased bulk density as expected at all depths in the upper and midslope (Table 1). On the upper slope, we predicted that bulk density would increase, from 1.14 g cm^{-3} in the upper 7.6 cm of the Memphis silt loam soil with no trafficking to 1.47 g cm^{-3} in soil with class-4 ruts (Fig. 1). The trend of increasing bulk density with increasing rut-class was similar at the 7.6-15.2 m and 15.2-22.9 cm sampling depths on both upper and midslope positions.

Much of the increase in bulk density associated with rut classes occurred with as little as 3.8 cm of rutting which is rut class 2 (Fig. 1). In the surface 1.6 cm of soil in the upper slope, predicted bulk density for rut class 1 was 1.14 g cm^{-3}. Rut class 2 was 1.33 g cm^{-3}, rut class 3 was 1.44 g cm^{-3}, and rut class 4 was 1.47 g cm^{-3}. Of the 0.33 g cm^{-3} increase from rut classes 1 to 4, rut class 2 accounted for 57 percent of the increase. Although we do not know the number of skidder turns for each of the rut classes, the large increase in bulk density with even the shallowest ruts again agrees with the results of other research in which most of the increase in bulk density due to trafficking occurred within three or four passes (Froehlich 1980, Guo and Karr 1988).

Partitioning the increase in bulk density due to trafficking can be difficult. We have observed that undisturbed soils normally increase in density with depth and that rutting may alter the position of soil within the horizon. In the process of making a rut, a skidder tire pushes part of the soil to the surface which forms a berm at the edge of the rut and compresses the soil at the base of the rut to a depth of 30 cm or more, making it very difficult to identify its original position in the soil horizon. Consequently, a 7.6-cm core taken at the bottom of the rut could be surface soil or a mixture of surface and subsoils. Our models indicate a 5 to 8 percent increase in bulk density in shallow ruts and over 20 percent increase in the ruts greater than 7.6-cm deep.

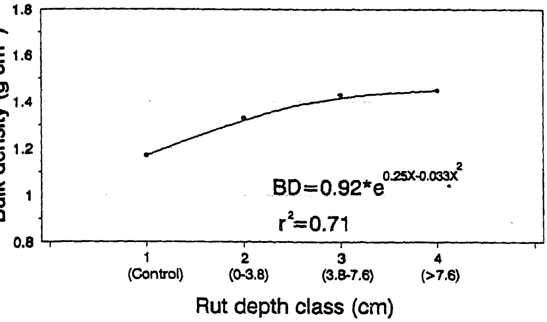
Slope position	Soil depth	Model*	R^2
	(cm)		
Upper	0-7.6	$BD = 0.92e^{0.25x-0.33x^2}$	0.71
		$MP = 84.73e^{-2.096x + 0.33x^2}$	0.83
	7.6-15.2	$BD = 1.285e^{0.054x}$	0.68
		$MP = 18.62e^{-1.14x + 0.167x^2}$	0.76
	15.2-22.9	$BD = 1.257e^{0.065x}$	0.72
		$MP = 13.82e^{-1.178 + 0.209x^2}$	0.54
Middle	0-7.6	$BD = 1.07e^{0.09x}$	0.60
		$MP = 114.25e^{-2.23x + 0.3588x^2}$	0.79
	7.6-15.2	$BD = 1.26e^{0.09x}$	0.59
		$MP = 40.42e^{-1674x + 0.267x^2}$	0.56
	15.2-22.9	$BD = 1.27e^{0.071x}$	0.73
		$MP = 50.85e^{-2.0x + 0.309x}$	0.55

* Where: BD = bulk density; MP = macroporosity; e = natural logarithm; x = rut class = 1 (control), 2 (0-3.8 cm depth), 3 (3.8-7.6 cm depth), 4 (> 7.6 cm depth).

Macroporosity

The loss of pores is not distributed equally through the range of pore sizes. In a previous study, Guo and Karr (1988) found that large macropores are more susceptible to alteration than the micropores.

Our models predicted the decrease in macroporosity very well in the first 7.6 cm of soil, with r^2 values of 0.83 for the upper slope and 0.79 for the midslopes (Table 1). Although the models predicting the decrease in macroporosity at deeper depths had lower r^2 values, the depth of the skidder rut continued to account for over 54 percent of the variation associated with its prediction (Table 1).



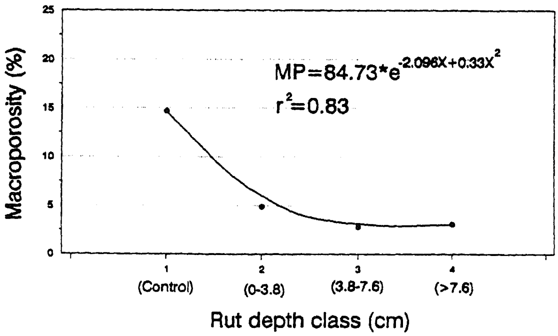


Figure 1. The effect of rut class (depth of skidder rut) on soil bulk density at the 0–7.6 cm soil depth in the upper slope.

Figure 2. The effect of rut class (depth of skidder rut) on soil macroporosity at the 0–7.6 cm depth in the upper slope.

Rutting decreased macroporosity by 67 percent in rut class 2 and by 80 percent in rut class 3 in the upper 7.6 cm of soil in both slope positions. Again, most of the change in macroporosity occurred within class-2 rut (Fig. 2). Loss of macroporosity continued through the 22.9-cm depth sampled, but was not as great (50 percent) as in the first 7.6 cm of soil, making the response curve more linear. Slope position had little influence on the decrease in macroporosity.

Rutting significantly increased bulk density and decreased macroporosity in the Memphis silt loam soil sampled. The models presented should aid foresters to schedule and manage logging operations that will minimize alterations in bulk density and macroporosity.

Acknowledgments

Approved for publication as Journal Article No. PS-7638 of the Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

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WATER RELATIONNS OF LOBLOLLY PINE SEEDLINGS IN NORTH-CENTRAL MISSISSIPPI [1]

Yanfei Guo, Bob L. Karr, and James Rachal [2]

Abstract. The purpose of this experiment was to study the effects of compacted soil and the absence or presence of the A soil horizon on leaf xylem pressure potential, and stomatal conductance of 1-year-old loblolly pine (Pinus taeda L.) seedlings. Soil compaction did not significantly affect water relations unless xylem pressure potential was greater than -1.2 MPa. The primary effects were from the presence of the A soil horizon which caused a significant decrease in water potential and conductance during the daytime. However, effect on conductance was only significant when predawn xylem pressure potential was above -0.6 MPa. As predawn xylem pressure potential dropped below -0.65 MPa, conductance steadily decreased although daytime xylem pressure potential did not change, and xylem pressure potential reached the lowest level earlier for seedlings planted in soil with the A horizon present. When predawn xylem pressure potential was above -0.6 MPa, a linear relationship existed between xylem pressure potential and conductance and the relationship was closer for the trees with compaction treatment than those without compaction.

Introduction

The effect of soil compaction on l properties and tree growth has n the focus of several studies. vious studies have revealed that compaction increases soil bulk ity and decreases porosity inbrenner 1955; Foil 1967; hlich et al., 1980; Gent et al.,). Soil strength is increased soil aeration may be negatively cted. Consequently, root growth often meets more resistance, and the development of roots may be affected by the lack of aeration (Hatchell et al., 1970). However, such studies have not investigated the effect of soil compaction on plant water relations, especially in loblolly pine (Pinus taeda L).

Previous studies in loblolly pine water relations indicate that water stress decreases transpiration (Brix 1962) and stomatal conductance (Seiler 1984). However, the relationship between leaf water potential and stomatal conductance is not linear. Teskey et al. (1986) reported that before xylem pressure potential decreased to -1.0 MPa, stomatal conductance dropped slowly. As xylem pressure potential dropped below -1.0 MPa, a decrease in xylem pressure potential caused a quick drop in stomatal conductance. It

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seems that under radiation, moderate temperature and vapor pressure defic conditions, the stomata of many plants remain open until a threshold lev of leaf water potential is reached. After that, any decrease of leaf wat potential will cause significant stomatal closure (Hall et al., 1976; fr Osonubi and Davies 1980). However, this relationship between xylem pre sure potential and stomatal conductance is not always close. Agnew a Carrow (1985) reported in a study of soil compaction on leaf water pote tial and stomatal resistance in Kentucky bluegrass (Poa pratensis L.) th stomatal resistance increased over a 5-day period under low soil oxyge but leaf water potential did not change. This phenomenon indicates th other factors besides the water potential of plants influence stomat activity.

The effect of soil compaction under actual field conditions on pla water relations may be even more complicated than what one may expect. northern Mississippi, logging traffic may create ruts and compact the soi particularly if it is wet. The A and E horizons of the soil are oft pushed outside the ruts. Trees planted in the ruts grow in a soil enviro ment different from trees planted in undisturbed soils that have not be rutted and may perform differently. The objective of this experiment w to study the effect of soil compaction and the presence or absence of the soil horizon on stomatal conductance and leaf water potential of loblol pine.

Materials And Methods

The experiment used a completely randomized design with two treatmen in a two-way factorial, for a total of four combined treatments: (1) no compacted with the A soil horizon absent (NC/AA); (2) noncompacted with t A soil horizon present (NC/AP); (3) compacted with the A soil horizon a sent (C/AA); and (4) compacted with the A soil horizon present (C/AP Each treatment was replicated four times.

The study site was located at the nursery on campus of Mississip State University. The annual average rainfall is 136 cm. A Memphis si loam soil (fine-silty, mixed, thermic Typic Hapludalfs) was compacted wi a construction compactor to a depth of 60 cm in plywood boxes measuring 2 x 120 x 60 cm. The boxes contained 40 cm of soil from the B soil horiz and 20 cm of soil from the A soil horizon for boxes with the A soil horiz present; otherwise, a box contained 60 cm of soil from the B soil horizo The average bulk density before compaction was 1.26 g/cm^{-3} for the A hor zon soil and 1.43 g/cm^{-3} for the B horizon soil. After compaction, avera bulk density for the A soil horizon was 1.43 g/cm^{-3} and 1.73 g/cm^{-3} for t B soil horizon. Twelve containerized loblolly pine seedlings were plant per box with a spacing of 25 x 40 cm. Seedlings were allowed to grow for months before water relation measurements were taken.

Beginning on 1 August 1989, a pressure chamber (PMS Inc., Corvalis, O was used to measure xylem pressure potential, and also a Li-cor 1600^{TM} po table porometer (Li-cor, Inc., Lincoln, NB) measured stomatal conductan of the seedlings. Measurements of xylem pressure potential were taken

predawn (3:00 a.m.), 9:00 a.m., and 2:00 p.m. every 10 days; and those of stomatal conductance were taken at 9:00 a.m. and 2:00 p.m. on the same day. Soil strength was measured by a penetrometer. Data were analyzed by analysis of variance (SAS 1988). Duncan's new multiple range test was used to separate treatment means, and linear regression was used to characterize possible relationships between xylem pressure potential and stomatal conductance.

Results And Discussion

Soil Strength

Soil compaction significantly increased soil strength, but the increase was greater in the soils with A soil horizon present (Fig. 1). For the surface 8 cm of soil, soil strength increased 63 percent in the soils with A soil absent, and 144 percent in the soils with A soil present. At 8-15 cm depth, the increase pattern of soil strength was similar to that for the surface 8 cm soil, but the degree of increase was smaller. At the transitional depth (15-24 cm) of the A and B horizon soils, soil strength was significantly lower in the compacted soils than in the noncompacted soils. At deeper depths, however, the pattern of soil strength was the same as the pattern in the surface soils.

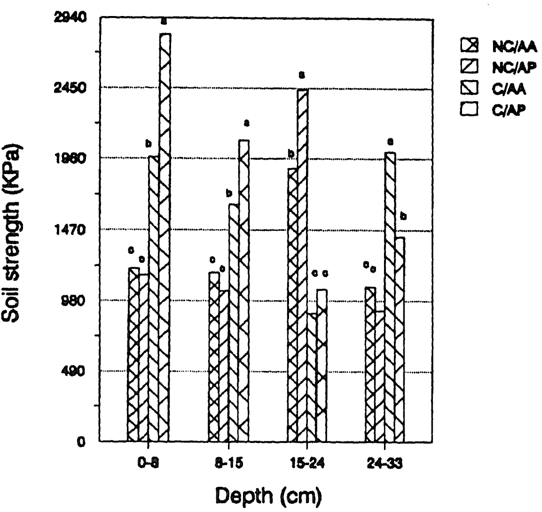


Figure 1. Effect of soil compaction on soil strength by depth of soil. Bars with the same letter are not significantly different at p =0.05.

Xylem Pressure Potential

Soil compaction significantly affected xylem pressure potential only one time (Fig. 2). Predawn xylem pressure potential decreased from -0.4 MPa in early August to -0.7 MPa in late August, indicating a depletion of soil water (Fig. 2a). In early September, predawn xylem pressure potential increased as a result of late-season rainfall. At 9:00 a.m. xylem pressure potential was not significantly different between treatments except on August 10 (Fig. 2b). At this time predawn xylem pressure potentials were greater than -0.6 MPa, and xylem pressure potential was higher than -1.2 MPa suggesting that soil moisture was not limiting. As average xylem pressure potential decreased to or below -1.2 MPa, the compacted soil treatment did not differ from the control at 9:00 a.m. and 2:00 p.m. (Fig. 2c).

In contrast to the effect of soil compaction on xylem pressure potential, the absence or presence of the A soil horizon influenced xylem pressure potential significantly during the daytime but had little effect on predawn xylem pressure potential (Fig. 3). The xylem pressure potential

at 9:00 a.m. was significantly lower for trees in the soils with the A soi horizon present than for those trees in the soils with the A soil horizo absent (Fig. 3b). This pattern continued through September 6 for 9:00 a.m measurements, but after August 10 the absence of the A soil horizon did no cause any change in xylem pressure potential at 2:00 p.m. (Fig. 3c).

The effect of the absence of the A soil horizon can be illustrated mor clearly by Figure 4. Xylem pressure potential on August 21 reached it lowest level much earlier during the daytime in the soil with the A soi horizon present than that with the A soil horizon absent. At 9:00 a.m. xylem pressure potential had already reached its lowest level for trees i the soil with the A soil horizon present, but the trees in the soil withou the A soil horizon did not reach this level until 2:00 p.m., which indi cates that under similar moisture conditions, the plant water defici created by the demand of transpiration came much earlier in the soil wit the A soil horizon present than that with the A soil horizon absent.

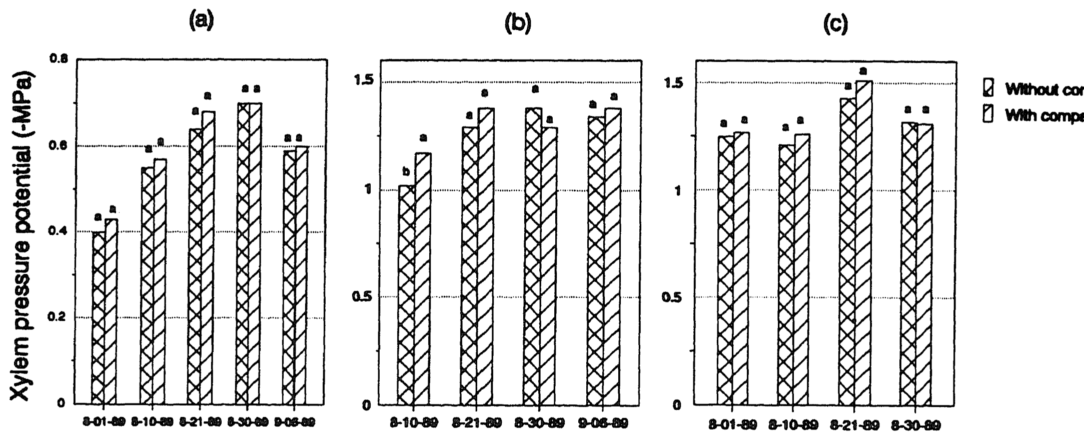
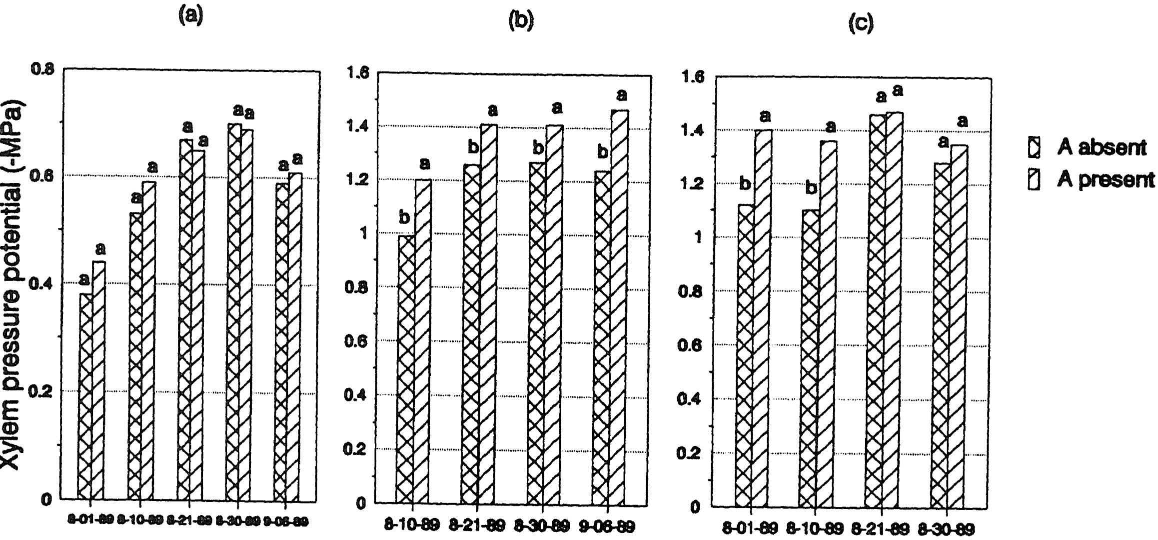


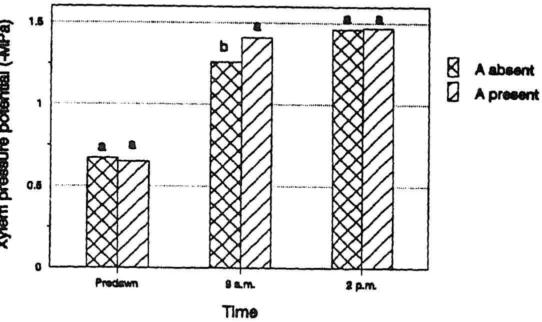
Figure 2. Effect of soil compaction on xylem pressure potential at predaw (a), 9:00 a.m. (b), and 2:00 p.m. (c). Bars with the same letter are no significantly different at p =0.05.

Stomatal Conductance

Soil compaction significantly influenced stomatal conductance only on time (Fig. 5), but stomatal conductance had a relatively greater variatio than xylem pressure potential. However, the change in stomatal conductanc corresponded fairly well to that of xylem pressure potential when predaw xylem pressure potential was higher than -0.6 MPa. When predawn xyle pressure potential dropped below -0.65 MPa, stomatal conductance did no correlate well with xylem pressure potential. Stomatal conductance de creased from August 21 to August 30 at 9:00 a.m., but xylem pressure po tential did not change at the same time (Fig. 2b, 5a). At 2:00 p.m. similar situation occurred from August 1 to August 10 (Fig. 2c, 5b). Sim ilar results were obtained by Agnew and Carrow (1985) in a study on the ef fect of soil compaction in Kentucky bluegrass. They reported that stomata resistance (reciprocal of conductance) steadily increased through a 5-da



igure 3. Effect of the presence or absence of the A soil horizon on xylem ressure potential at predawn (a), 9:00 a.m. (b), and 2:00 p.m. (c). Bars ith the same letter are not significantly different at p =0.05.



igure 4. Effect of the presence or bsence of the A soil horizon on ylem pressure potential on 21 ugust 1989. Bars with the same etter are not significantly dif- erent at p =0.05.

period under low soil oxygen while leaf water potential remained about same. The results indicate that factors other than xylem pressure potential also affect stomatal activity.

The influence of the absence of the A soil horizon on stomatal conductance was interesting. Unlike xylem pressure potential, stomatal conductance measured at 9:00 a.m. was significantly different only on August 10 and on September 6 (Fig. 6a). On August 21 and 30, stomatal conductance did not show any difference between treatments, although xylem pressure potential was ignificantly different at the same time (Fig. 6a, 3b). Again, this indiates that stomatal conductance can be affected by factors other than plant ater potential.

elationship between Stomatal Conductance And Xylem Pressure Potential

As mentioned earlier, xylem pressure potential was related to stomatal onductance when predawn xylem pressure potential was above -0.6 MPa. A inear model was fitted to the data, and we found that there was a fairly

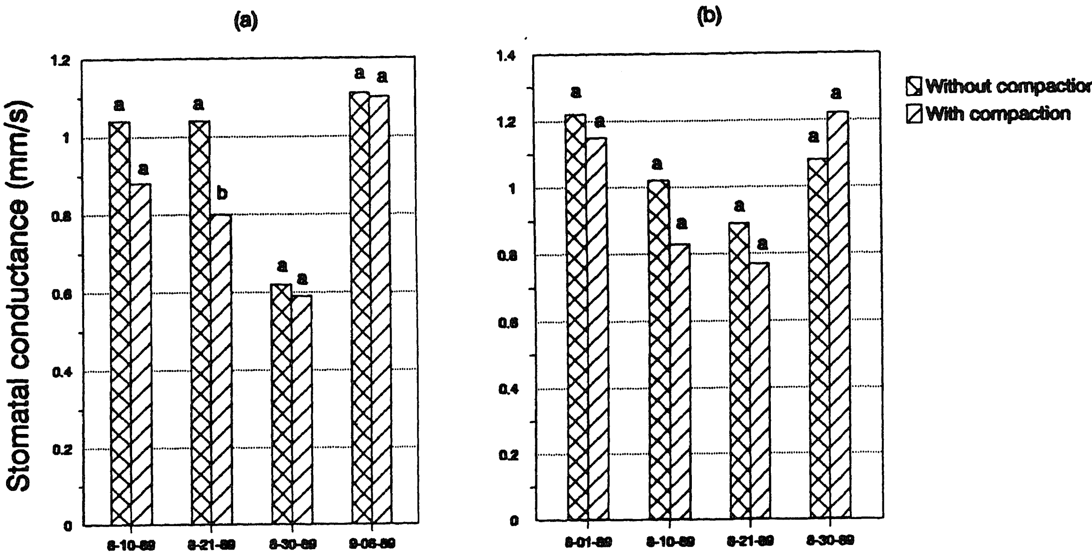


Figure 5. Effect of soil compaction on stomatal conductance at 9:00 a.m. (a) and 2:00 p.m. (b). Bars with the same letter are not significantly different at p =0.05.

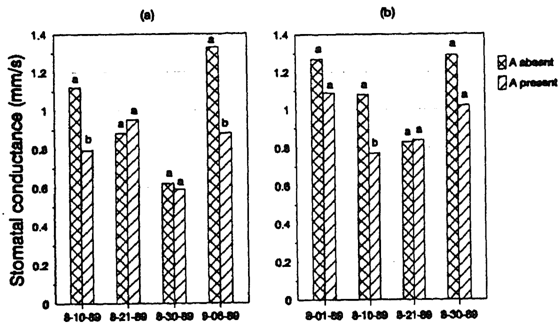


Figure 6. Effect of the presence or absence of the A soil horizon on stomatal conductance at 9:00 a.m. (a) and 2:00 p.m. (b). Bars with the same letter are not significantly different at p =0.05.

strong relationship between them at 9:00 a.m. on August 10 (r^2 were 0.64 and 0.62 for compacted and noncompacted soils, respectively) when predawn xylem pressure potential was above -0.6 MPa (Fig. 7a). At 2:00 p.m., however, the relationship was even stronger for the trees in compacted soils (r^2 was 0.79) than those in noncompacted soils (r^2 was 0.15) (Fig. 7b). On August 21 when predawn xylem pressure potential was lower than -0.65 MPa, indicating a drier soil, xylem pressure potential and stomatal conductance were not strongly related (Fig. 7c). Similarly, on 30 August at 9:00 a.m. the relationship was not strong (r^2 was 0.51 and 0.50 for compacted and noncompacted soils, respectively) (Fig. 7d). As soil moisture improved in early September, the relationship became much closer for compacted treatment (r^2= 0.80) than for noncompacted treatment (Fig. 7e).

The reason that xylem pressure potential was more closely related with stomatal conductance in compacted soil treatment is not clear. This seems to happen when soil moisture conditions are relatively good, and ambient

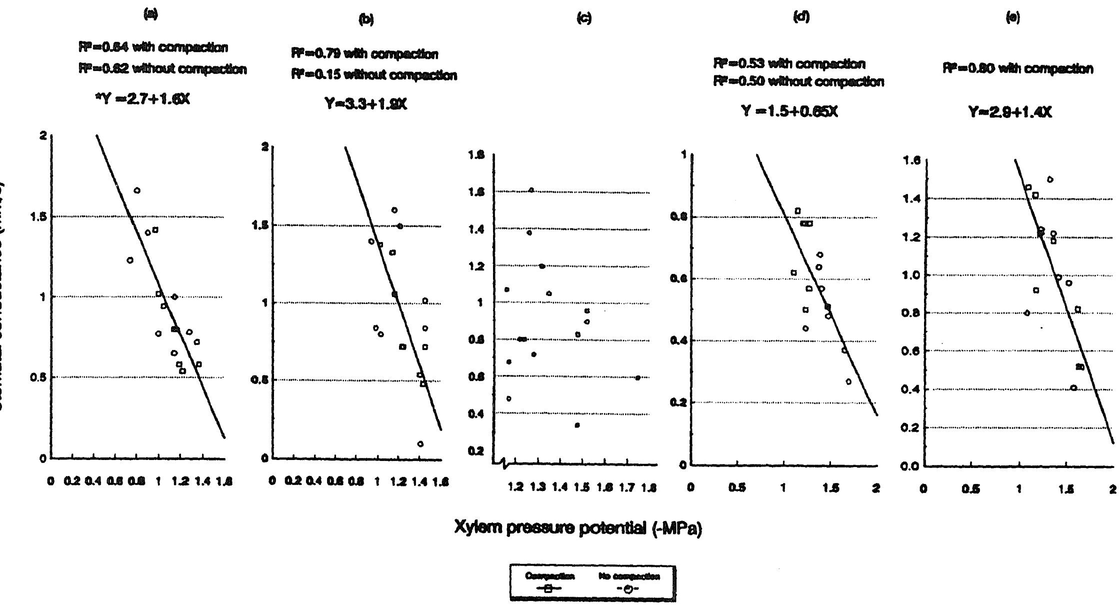


Figure 7. Relationship between xylem pressure and stomatal conductance at 9:00 a.m. (a) and 2:00 p.m. (b) on 10 August 1989; 9:00 a.m. on 21 August 1989; 9:00 a.m. on 30 August 1989, and; 9:00 a.m. on 6 September 1989.

transpirational demands are high. For the soil used in this study, soil compaction did not generally affect xylem pressure potential and stomatal conductance. However, the variation in stomatal conductance was higher for the trees in the control than for those in compacted soil treatment. It could be that the roots of the trees in the compacted soil had better contact with the soil and were able to absorb water more easily than those in the control soils.

The linear relationship between xylem pressure potential and stomatal conductance for this study corresponds with the work done by Teskey et al. (1986) except that the range of xylem pressure potential for this study was narrower. The xylem pressure potential measurements taken in this study during the daytime were distributed between -0.9 and -1.5 MPa. Within this range of xylem pressure potential, Teskey et al. (1986) found that stomatal conductance decreased rapidly. A similar trend occurred in this study. However, the relationship between xylem pressure potential and stomatal conductance in the higher range (greater than -0.9 MPa) could not be estimated because the xylem pressure potentials and the corresponding stomatal conductances were not measured. Consequently, the regression equations developed in this study are only for the data range that the study covered.

In summary, soil compaction greatly increased soil strength but did not significantly affect the water relations of the trees except when xylem pressure potential was higher than -1.2 MPa. The presence of the A soil

horizon significantly affected the water relations of the trees at 9:00 a.m. and at 2:00 p.m. when predawn xylem pressure potential was higher than -0.6 MPa. Xylem pressure potential and stomatal conductance were lower for the trees in the soils with the A soil horizon present. As predawn xylem pressure potential dropped below -0.65 MPa, indicating a drier soil, stomatal conductance continuously decreased as xylem pressure potential remained about the same level. The relationship between xylem pressure potential and stomatal conductance was closer for the compacted treatment than for the noncompacted treatment.

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SOIL PROPERTIES RELATING TO HEIGHT GROWTH OF LOBLOLLY PINE ON FOUR MAJOR SOIL SERIES IN EAST TEXAS [1]

R. Larry Willett and M. Victor Bilan [2]

Abstract. Stem analysis was used to obtain age and height data for loblolly pine (Pinus taeda L.) stands growing on Bowie, Fuquay, Sacul, and Troup soils in northeastern Texas. The soil profiles were described and bulk soil samples were taken in each sample stand. Selected physical and chemical soil properties were measured for each soil horizon. Stepwise regression analysis was used to correlate average stand height at ages 5, 10, 20, and 30 years with soil properties. Strong associations were found between stand height and properties which relate to available soil moisture holding capacity, soil permeability, and soil aeration. For Bowie, Fuquay, and Troup soils, average stand height increased with increasing moisture holding capacity of the surface soil and with increasing subsoil permeability and aeration. On Sacul soils, height increased with better permeability and aeration of the solum. Average annual height growth on the four soils differed significantly only in the first 5 years, peaked between ages five and 10, and then declined. Average cumulative stand heights differed significantly between series until age 10. Differences in attained height at age 25 seemed more related to rapid early growth than to differences in later growth rates.

Introduction

Site index for loblolly pine (Pinus taeda L.) has been found to increase with increasing thickness of the A horizon (Coile 1952, Coile and Schumacher 1953) or depth to the least permeable horizon (Gaiser 1950), especially in shallow soils. This relationship, however, seems to be curvilinear (Ralston and Barnes 1955). As depth of surface soil increases, its effect on growth decreases and may become negative (Zahner 1958). In one study, 18 inches of surface soil seemed optimum for pine growth (Zahner 1957, 1958). Greater thicknesses were apparently not used, and surface soil below 18 inches seemed to function as a subsoil.

The Sacul, Fuquay, and Troup soil series all have an average site index of 80 for loblolly pine at age 50, while the Bowie series averages 83 (Dolezel 1975). These soils are all Udults, having formed under similar warm, moist climatic conditions from Coastal Plain sediments. They are all old, highly-weathered soils with low base saturation and have some degree of clay accumulation in the subsoil.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Sacul soils consist of 5 to 15 inches of fine sandy loam over a clayey subsoil (USDA 1976a). They have a perched water table during part of the year. Bowie soils are similar to Sacul soils in having relatively shallow surface soils, 9 to 20 inches of fine sandy loam, but different in having a sandy clay loam rather than clayey subsoil (USDA 1976b). A fragipan may be present in Bowie soils.

Fuquay soils have a surface layer of from 20 to 40 inches of loamy fine sand (USDA 1969a). The subsoil extends to a depth of 80 to over 100 inches and consists of fine, sandy loam overlaying sandy clay loam. The Fuquay series has plinthite in its subsoil. The Troup series is distinguished by an extremely thick (> 40 inches) loamy, fine sand A horizon (USDA 1969a).

Considering the demonstrated importance of surface soil thickness, the variation present in Bowie, Fuquay, Sacul, and Troup soils would be expected to cause significant differences in site quality. The lack of such differences stimulates speculation. Is surface depth not a determining factor of site index, but rather only coincidentally correlated with a true determining factor which has not been measured? Do compensating factors exist in these soils? Are there differences in rate of height growth at younger ages that are no longer apparent at later ages?

This study was conducted, therefore, in order to examine the relationship of surface soil thickness to site index in Bowie, Fuquay, Sacul, and Troup soils and to see whether limiting soil factors change with stand age.

Methods

Study Area

The study area included roughly the northern half of the pineywoods of east Texas. This forested area has a humid climate, with hot summers and mild winters. Precipitation totals average 40-46 inches annually, and precipitation is fairly well distributed throughout the year (USDC 1969).

Data Collection And Analysis

Ten stands were sampled on Bowie soils, eleven on Fuquay, twelve on Sacul, and six on Troup soils. Samples were taken in stands of loblolly pine which were at least 30 years of age and which did not show evidence of suppression, high grading, or other bias-causing agencies. One plot, varying in size so as to include four dominant trees on a uniform soil, was located in each stand.

Increment cores were taken from each sample tree at breast height (4½ ft) and at each 10-ft height interval starting at 10 ft from the ground and going to the top of the tree. Some samples were taken at logging operations and others by climbing the trees. Total height was measured either with a tape or by using a clinometer.

After the annual rings were counted, the adjustment recommended by Lenhart (1974) was used to approximate the apex of annual height growth for tree ages at each sampling interval. Age-height relationships were plotted

for each of the four sample trees within each stand and a curve was fitted through the points. For each stand, the average tree height at 5-year age intervals was read from the curve and used in subsequent statistical analysis.

At each plot, a soil profile description was made and a bulk soil sample was taken from each soil horizon. The soil samples were analyzed to determine texture, organic matter, pH, soluble salt, calcium, magnesium, potassium, sodium, and phosphorus. Percent moisture retention was measured by extraction at field capacity (0.33 bars) and permanent wilting point (15 bars) (Richards 1947, 1954; USDA 1972). Available water capacity was approximated from soil texture data (Broadfoot and Burke 1958).

Statistical Analysis

For each soil series, the range of stand heights (from stem analysis data) at ages 5, 10, 20, and 30 years were examined separately. The data were also pooled and analyzed as a group. Based on scatter diagrams and correlation analysis, soil variables which seemed unrelated to stand height for specific soil/age combinations were deleted from further testing. For each soil and age combination, stepwise regression analysis techniques were used to derive regression equations for predicting average stand height based on measured soil properties. Statistical significance were determined at the 5-percent level unless stated otherwise.

Results And Discussion

Age-height Relationships

A comparison of cumulative stand heights on the four soil series showed that significant ($p < 0.05$) differences between soils existed only at ages 5 and 10 years. At these ages, stands growing on the Bowie soils had the greatest average heights, while stands on Sacul soils were the shortest on the average. Stands growing on Fuquay and Troup soils were intermediate. Height differences between stands on Fuquay and Troup soils were not statistically significant.

After age 10, differences in average stand height on the four soils were not significant. On the average, however, total stand height was greatest at all ages on Bowie soils and least on Sacul soils (Fig. 1). Stand heights on Troup and Fuquay soils were intermediate and had nearly identical average cumulative heights with less than a foot of difference in height at every age. It appeared that differences in stand height were established at a young age on these four soils and that the relative height ranking was still maintained at age 30.

In addition to total height, average annual height increment by 5-year intervals was also compared. This showed a significant ($p < 0.05$) difference in growth between all four soils during the first 5 years. Stands growing on the Bowie soils had the greatest average annual height increment and those on Sacul soils had the least (Fig. 1). Fuquay and Troup were intermediate, with stands on Fuquay soils having faster growth than those on the Troup soils.

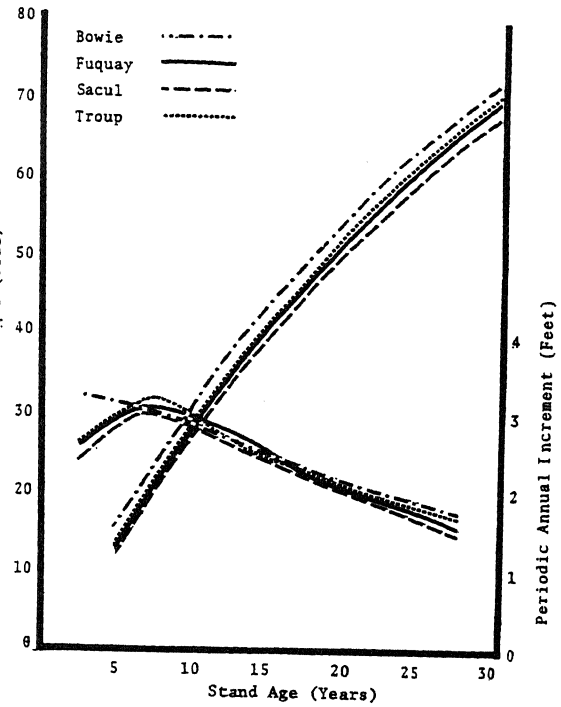

Figure 1. Average cumulative height and periodic annual increment for stands growing on Bowie, Fuquay, Sacul, and Troup soils.

There was no significant difference in stand growth on the four soils between the ages of 5 and 30 years. On all four soils, the greatest average annual height growth occurred by the age of 10 and the rate of growth declined steadily after that.

The data suggest that good sites established differences in height early in the life of the stand and that much of the difference in site index may be expressed by age 5 or 10 years. It is not possible to conclude from the data that soil is the sole determining factor, however. Differences in early growth might be due to soil factors, competition, or a combination of the two.

Bowie Soils

The regression to predict stand height at age 5 on Bowie soils was highly significant ($p < 0.01$), and significant ($p < 0.05$) regressions were obtained for stand height at ages 10, 20, and 30 years. The percent of variation accounted for by the regressions was 84, 80, 78, and 72 percent, respectively. Table 1 presents a summary of soil factors used to predict stand heights. The equations to predict stand height at age 5, 10, 20, and 30 years on Bowie soils are:

$$HT5 = 47.128 + 1.720X_1 - 0.481X_2 - 0.335X_3$$
with $R^2 = 0.8447$, *

$Sy.x = 1.1107$, ** and

where HTn = stand height in feet at that stand age, and
X_n = variables identified in the accompanying table for the soil series;

$$HT10 = 24.245 + 1.578X_1 - 1.460X_4 - 0.343X_2$$
with $R^2 = 0.7997$ and $Sy.x = 2.0276$

$$HT20 = 27.119 + 1.131X_6 + 1.080X_7 - 3.617X_8$$
with $R^2 = 0.7815$ and $Sy.x = 3.7652$

* $R^2 \times 100$ = percent of height variation accounted for by the regression

** Sy.x = standard error of the estimate

$$HT5 = 7.419 + 0.347X_9 - 0.192X_{10},$$
$$\text{with } R^2 = 0.8453 \text{ and } Sy.x = 0.6687$$

$$HT10 = 72.366 - 0.491X_{11} - 0.273X_2,$$
$$\text{with } R^2 = 0.7285 \text{ and } Sy.x = 0.6606$$

$$HT20 = 63.330 + 1.783X_{12} + 0.256X_{13} - 0.383X_3 - 3.692X_4$$
$$\text{with } R^2 = 0.8395 \text{ and } Sy.x = 2.3020$$

$$HT30 = 83.999 + 0.441X_{13} + 2.179X_{12} - 0.548X_3 - 5.164X_4$$
$$\text{with } R^2 = 0.9231 \text{ and } Sy.x = 2.1291.$$

Fuquay soils have a well-drained A horizon consisting of 20-40 inches of sand or loamy sand (USDA 1969a), and height growth of loblolly pine was favored by the increase in available water supply associated with a higher content of fine material in the surface soil.

At the same time, growth was improved by factors which act to reduce water-logging and prevent perched water tables in the subsoil. Fuquay soils have a sandy clay or sandy clay loam subsoil with moderate permeability in the upper B horizon and slow permeability below (USDA 1969a). During wet periods, there is commonly a perched water table above the plinthic zone which begins at a depth of 45-60 inches. Height growth improved with greater sand content of the subsoil, which improves downward percolation of water, and with a slight degree of slope, which allows lateral water movement.

Sacul Soils

It was not possible to derive a significant regression relating stand height at age 5 years to measured soil factors on the Sacul soils. Significant ($p < 0.05$) regressions were obtained for stand height at ages 10, 20, and 30, however. These regressions accounted for 68, 53, and 33 percent of the variation in stand height, respectively. The soil factors used to predict stand height on Sacul soils are summarized in Table 3. The equations derived from these factors are:

$$HT10 = 33.007 - 0.429X_{14} - 0.526X_1 + 0.007X_{15}$$
$$\text{with } R^2 = 0.6776 \text{ and } Sy.x = 2.3096$$

$$HT20 = 51.761 = 0.395X_{14} + 0.218X_{10}$$
$$\text{with } R2 = 0.5341 \text{ and } Sy.x = 3.9880$$

$$HT30 = 58.126 + 0.381X_{16}$$
$$\text{with } R^2 = 0.3343 \text{ and } Sy.x = 4.9188.$$

Moisture-related properties seemed to be the key to productivity in the Sacul soils. The surface of Sacul soils consists of about 12 inches of fine sandy loam, sandy loam, or loam (USDA 1976a). The B2 horizon consists of silty clay or clay and has a clay content of from 35-50 percent. The lower B2 horizon and B3 horizon are silty clay loam, clay loam, sandy clay loam, or silt loam. The A-plus-B ranges from 40 to 72 inches thick. The

permeability of the B2 horizon to water movement is about one-tenth that of the A horizon. There is more available soil water in the B2 than the A horizon but most of it occurs in the B24 and B3 horizons, which are somewhat coarser-textured than the B2. There are few if any pores of larger than capillary size in Sacul subsoils, and near-saturation of the soil occurs above the water table.

Table 3. Soil factors used to predict stand height at ages 5, 10, 20, and 30 on Sacul soils.

Variable	Soil factor	Relation to height at stand age: 5	10	20	30
X_{14}	Depth to mottling (inches)		–	–	
X_1	Water-holding capacity of A horizon (inches)		–		
X_{15}	Subsoil moisture retention (percent m.r. at 0.33 bar- percent m.r. at 15 bars) X (horizon thickness in inches) summed for all B horizons		+		
X_{10}	Weighted average percent silt of B horizon, not including B1			+	
X_{16}	Weighted average percent silt of A-plus-B1 horizons				+

It would appear that good aeration is more important than high moisture lding capacity in the surface of Sacul soils. Stand height at age 10 is gatively correlated with available water holding capacity of the A hori- but height is positively correlated with moisture holding capacity of subsoil. Since the surface soil is fairly shallow in Sacul soils, even seedling would be able to draw on subsoil moisture reserves after the face soil moisture is exhausted. On the other hand, poor aeration in erlogged surface soil would cause heavy mortality of the small feeder ts which are concentrated in the upper soil.

In view of this, it was unexpected to find that height was negatively related with depth to mottling at ages 10 and 20. Mottling indicates the soil is subject to alternate wetting and drying and that the hor- is saturated during part of the year. Generally, greater depth to ling has been found to be related to higher site index, especially on ly drained soils (Coile 1952). Since the reverse was true on these l soils, it may indicate that the B horizon is saturated (and thus, re- ged) with water during the dormant season but not during the growing on when poor soil aeration would be most harmful to tree roots.

Stand height at age 20 was favored by increasing silt content of the subsoil. Increasing subsoil silt in the range encountered in the samples (5-34 percent) brings the soil texture closer to a loam or silt loam. Although total water holding capacity is greater on heavier-textured soils, loam and silt loam soils have greater plant-available water holding capacities than soils of other textures (Buckman and Brady 1969).

Height at age 30 increased with increasing silt content of the surface soil in the range of 9-35 percent. Increasing silt content in this range would increase available water without causing poor aeration.

<u>Troup Soils</u>

Several samples which had been taken as Troup soils were found upon later examination to have non-typical profiles. Those samples, which had Troup profiles developing over older Ruston soils, were dropped from the analysis. Few 30-year-old stands of loblolly pine were encountered on Troup soils, and it was not possible to replace the deleted samples. The small number of remaining samples makes it difficult to assign meaningful significance values to the regressions.

It was not possible to derive a statistically significant regression relating soil factors to stand height at age 5 years on the Troup soil. Highly significant ($p < 0.01$) regressions were obtained for ages 10, 20, and 30, however. These regressions accounted for 96, 97, and over 99 percent of the variation in stand height, respectively. The soil factors used in these regressions are presented in Table 4. The equations to predict stand height on Troup soils are:

$$HT10 = -1.274 + 0.597X_{17} + 12.703X_4$$
with $R^2 = 0.9600$ and $Sy.x = 1.1295$

$$HT20 = 55.805 + 0.713X_{17} - 3.118X_{10}$$
with $R^2 = 0.9692$ and $Sy.x = 1.0877$

$$HT30 = 53.839 + 1.031X_{17} - 6.492X_{10} + 2.436X_8$$
with $R^2 = 0.9998$ and $Sy.x = 0.1393$.

At ages 10, 20, and 30, stand height increased with increasing organic matter content of the A horizon. Troup soils have 40-72 inches of sand or loamy sand overlaying a sandy loam or sandy clay subsoil which extends to a depth of from 80 to over 120 inches (USDA 1969b). Organic matter would thus favor growth by increasing the water-holding capacity of these deep, coarse-textured soils as well as providing nutrients.

Average stand height at age 30 increased with increasing water-holding capacity of the solum. This is logical and could be expected for sandy, droughty soils such as these.

Simple linear regression showed stand height to increase with increasing silt content of the subsoil and also with decreasing subsoil sand content (larger values of the texture-depth index). However, these stand height-soil relationships were reversed when the soil variables were fixed

of the sub-
related to growth. This seems unreason-
able, considering the relatively small amount of fine material present in these deep coarse-textured Troup soils. The role of subsoil silt in Troup soils is unclear and its inclusion in the height prediction equations may be due to chance variation in the small sample.

Table 4. Soil factors used to predict stand height at ages 5, 10, 20, and 30 on Troup soils.

Variable	Soil factor	Relation to height at stand age: 5	10	20	30
X_{17}	Percent organic matter X inches horizon thickness, summed for all A horizons		+	+	+
X_4	Weighted average percent sand of B horizon/thickness (inches) of A horizon		+		
X_{10}	Weighted average percent silt of B horizon, not including B1			−	−
X_8	Water-holding capacity of A-and-B horizons (inches)				+

mbined Data - All Soils

It was possible to derive significant ($p < 0.05$) regressions using po-
ed data for Bowie, Fuquay, Sacul, and Troup soils. As might be expected,
wever, the regressions were much weaker than those for the individual
ils. Since none of the regressions using combined data accounted for
re than 29 percent of the variation in stand height, they will not be
esented in this paper.

Conclusions

Strong associations were found between stand height and soil propert-
, particularly those which relate to available soil moisture- holding
acity, soil permeability, and soil aeration. Both surface soil and sub-
l properties were important, and the growth-limiting factors seemed to
with stand age.

The thickness of the A horizon was not clearly related to height growth
loblolly pine during the first 30 years after stand establishment on
e, Fuquay, Sacul, and Troup soils. Rather, the most important proper-
of the surface soil were related to its available moisture-holding

capacity. Stand height increased on Bowie, Fuquay, and Troup soils with increasing water holding capacity of the surface soil. In contrast, on the finer-textured Sacul soils, permeability and aeration seemed to be a limiting factor even in the surface soil and stand height was negatively related to water holding capacity of the surface soil.

The thickness of the soil layer, which is favorable for root growth, did seem to be related to height growth. A readily permeable, well-aerated subsoil was necessary for good growth of loblolly pine on all four of the soil series. The soils which lacked these qualities had a shallow effective rooting depth which inhibited development of a deep, extensive root system and they were associated with slow-growing stands of loblolly pine.

The soil factors which controlled growth of loblolly pine stands on these four soils varied with stand age. In general, surface soil characteristics were most important for young stands. The root systems of young trees must be in contact with sufficient soil water to supply the needs of the plants during the dry summer months. In the Bowie, Fuquay, and Troup soils, this moisture was obtained when the surface horizons had a high water-holding capacity. Stands growing on Sacul soils seemed to be favored by a well aerated A horizon overlying a moist subsoil which was within reach of the root systems of the young trees.

At later ages, when the root systems more completely occupied the soil, the characteristics of the subsoil became more important. In all four soils, a permeable, well aerated subsoil apparently enabled the establishment of a deep, widespread, healthy root system and was associated with the best growth of loblolly pine.

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ARE PINE PLANTATION WINDROWS A SOURCE OF NUTRIENTS FOR THE NEXT ROTATION? [1]

Charles A. Gresham [2]

Abstract. Three 17-year-old loblolly pine (Pinus taeda L.) plantations in the lower Coastal Plain of South Carolina were selected for intensive soil sampling. Within each plantation, bed, interbed and windrow zones were sampled separately in each of 15 plots at two depths. Samples were analyzed for total, ammonium and nitrate nitrogen, and extractable phosphorus, potassium, calcium and magnesium. Organic matter, pH and bulk density were also determined. Windrow zones had significantly higher concentrations of all nutrients measured. Concentrations of extractable magnesium, calcium, all forms of nitrogen, and organic matter in windrow samples were twice that of bed or interbed samples. Although potassium, magnesium, calcium, and nitrate-nitrogen were concentrated in the windrows, the absolute amounts on a kg ha^{-1} basis were not high enough to consider windrow soil a significant nutrient source for the next rotation of loblolly pine.

Introduction

Many natural pine and pine-hardwood forests have been converted to loblolly pine (Pinus taeda L.) plantations. The operational technique often used involved clearcutting the existing stand, shearing stumps and residual stems and pushing the debris into windrows. This left a clean site for bedding and planting or simply flat-planting seedlings for the next rotation. As a result of this technique, 10 to 25 percent of the site was occupied by windrows composed of residual biomass and topsoil.

Sensitivity to decreased site productivity due to topsoil displacement into windrows (McClurkin and Moehring 1978, Burger 1983) led to the use of equipment and techniques that move only the biomass into the windrows, with little soil displacement. Soil-laden windrows must be dealt with when the pine plantation is harvested and site preparation techniques are prescribed for establishing the next rotation.

Two questions arise when deciding how to handle windrows during site preparation for the second rotation. First, are soil nutrient concentrations still higher in windrows than in planted beds at the time of harvest? If so, are these nutrient-rich windrows a significant source of nutrients for the next rotation?

This report presents data to answer these questions for loblolly pine plantations in the lower Coastal Plain of South Carolina.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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Three intensively site-prepared and bedded loblolly pine plantations at least 16 ha in area, with a minimum stocking of 740 stems ha^{-1}, and a minimum 25-year site index of 21 m, were used for the study (Table 1). Stands 1 and 3 were in Georgetown County, in South Carolina's lower Coastal Plain, and Stand 2 was in Williamsburg County, in South Carolina's middle Coastal Plain. Stand 3 did not contain windrows and was thinned 4 years prior to sampling by removing every seventh row, followed by selective thinning.

Table 1. General characteristics of three loblolly pine plantations in South Carolina's lower Coastal Plain.

Soil series	Stand 1 Bladen loam	Stand 2 Lynchburg sandy loam	Stand 3 Wahee fine sandy loam
Drainage class	Poorly drained	Somewhat poorly drained	Somewhat poorly drained
Site preparation	Shear, rake, bed	Shear, rake, bed	Bed
Basal area (m^2ha^{-1})			
Loblolly pine	34.2(0.9)*	30.2(1.2)	21.9(0.5)
Total	36.7(0.8)	31.8(1.1)	22.8(0.6)
Stocking (stems ha^{-1})			
Loblolly pine	1017(43)	877(40)	775(17)
Total	1193(45)	1006(36)	883(15)
Tree age (yr)	17	20	18

* mean (standard error of the mean)

Sixteen to 24, 61 by 61 m main plots were systematically installed in nds 1, 2, and 3 in 1986, 1987, and 1988, respectively. The number of ts installed was proportional to plantation size. A 15-m buffer strip arated each main plot from adjacent main plots and from areas of the ntations not included in the study. One or two 35 by 20-m subplots were ated in each main plot to produce a total of 15 subplots per stand. All plots included sections of all three zones except subplots in Stand 3 ch did not contain windrows. The subplot long axes were perpendicular the long axes of the windrows. Species and diameter at breast height) were tallied for every live tree (dbh > 7 cm) in each subplot.

Composite soil samples were collected at two depths (0 to 15 cm and 15 to 30 cm) from each zone (windrow, bed, interbed) within each subplot. Soil samples were collected in the winter of the year that the main plots were installed. Ten to 12 soil cores were taken with a 1.9-cm diameter core sampler, mixed by hand in the field, and the resulting composite sample was then split for analysis.

Clemson University's Agricultural Chemical Services analyzed one set of samples for extractable phosphorus, potassium, magnesium and calcium. Samples were air-dried and extracted with Mehlich I extraction reagent (Isaac et al., 1983). Potassium, calcium, and magnesium analyses were by atomic absorption spectroscopy. Phosphorus was determined colormetrically by the ascorbic acid method (Murphy and Riley 1962).

Total Kjeldahl nitrogen, nitrate-nitrogen, ammonium-nitrogen, organic matter and pH were determined on the other set of samples. Total Kjeldahl nitrogen was determined by block digestion in sulfuric acid with potassium sulfate and copper sulfate. The diluted digestate was analyzed on a Technicon^{tm} Auto Analyzer II. Samples were extracted in 2.0 M KCl and were analyzed for nitrate-nitrogen by the cadmium reduction method (Keeney and Nelson 1982) and for ammonium nitrogen by the indophenol blue method (Keeney and Nelson 1982). Organic matter was determined with a LECO Model 572-200 semiautomatic carbon determinator, and pH was determined by glass electrodes, using a 1:2 ratio of soil to water. Five soil bulk density samples were collected in each zone at both depths in three subplots of each stand with a 92 cm^3 core sampler. The 15 to 30 cm depth was not sampled in Stand 1 due to a high groundwater table. Samples were dried at 105°C to a constant weight. Stand 1 was measured in 1986, and Stands 2 and 3 were measured in 1989.

Ground elevation at 60-cm intervals across the windrow was measured along two transects, each perpendicular to the windrow main axis in each plot of Stand 2. Windrow cross-sectional area was calculated for each transect by the trapezoidal rule and averaged over the 43 transects measured.

Results And Discussion

Seventeen to 20 years after site preparation, soils of the windrow zone had significantly higher concentrations of phosphorus, potassium, magnesium, calcium, total Kjeldahl nitrogen, ammonium nitrogen, nitrate nitrogen, and organic matter than the bed or interbed zones. Windrow soil phosphorus, potassium, magnesium, total Kjeldahl nitrogen, and ammonium nitrogen concentrations were 1.5 to 2.0 times the concentrations of bed or interbed zone soil. Calcium concentrations of windrow soils were approximately three times the bed and interbed concentrations. The biggest soil nutrient concentration difference between windrows and bed or interbed zones was in nitrate nitrogen concentrations. Windrow soil nitrate nitrogen concentrations were four to five times that of bed and interbed zones.

This concentration of nutrients probably resulted from topsoil dis-acement into the windrows during site preparation and mineralization of trients from the residual biomass in the windrows. The fact that wind-ws were quite distinct 17 to 20 years after construction indicated that ere was mineral soil in the windrow. Also, we had little trouble getting mineral soil sample from windrow zones. The presence of decomposed or-nic matter in the windrows is supported by the windrow soil organic mat-r content which was approximately twice that of bed or interbed zones.

These results indicate that 17 to 20 years after site preparation, nu-ient concentrations were higher in windrow zones than in bed or interbed nes. To answer the second question, whether or not the windrows were a gnificant source of nutrients for the next rotation, soil bulk density d windrow volume data were used with the soil nutrient concentration data estimate the size of windrow nutrient pools. Average windrow cross sec-on area was 2.08 m^2 and average windrow width was 7.58 m. For Stand 1, which windrows occupied 17.3 percent of the site, windrow volume was 475 ha^{-1}; for Stand 2, in which windrows occupied 10.1 percent of the site, ndrow volume was 278 m^3 ha^{-1}.

Windrow soil nutrient pool size estimates are summarized in Tables 2 d 3. On a percent basis, windrows zones contain more potassium, magnes-m, calcium, ammonium nitrogen, nitrate nitrogen and total nitrogen than pected by the relative area occupied. For example, in Stand 1, 19.1 per-nt of the site potassium pool (windrow + bed) is in the windrows, even ough they occupy only 17.3 percent of the stand area. However, windrow nes contain relatively small absolute amounts of these nutrients. Wind-ws could supply only 1.0-1.3 kg ha^{-1} of phosphorus and 1.2-2.4 kg ha^{-1} of monium nitrogen.

Table 2. Soil nutrient pools of Stand 1, a 17-year-old loblolly pine plantation in South Carolina's lower Coastal Plain.

Nutrient	Content		Proportion	
	Windrow	Bed	Windrow	Bed
	--- (kg ha^{-1}) ---		---- (percent) ----	
Phosphorus	1.3	6.8	16.4	83.6
Potassium	11.1	46.9	19.1	80.9
Magnesium	17.7	48.5	26.7	73.3
Calcium	161.8	286.2	36.0	64.0
Ammonium N	2.4	14.3	14.2	85.8
Nitrate N	2.2	4.4	33.9	66.1
Total N	417.4	2799.4	13.0	87.0
Area occupied	--	--	17.3	82.7

Table 3. Soil nutrient pools of Stand 2, a 20-year-old loblolly pine plantation in South Carolina's lower Coastal Plain.

Nutrient	Content		Proportion	
	Windrow	Bed	Windrow	Bed
	--- ($kg\ ha^{-1}$) ---		---- (percent) ----	
Phosphorus	1.00	15.00	6.2	93.8
Potassium	4.10	44.00	8.6	91.4
Magnesium	5.10	23.20	18.0	81.2
Calcium	47.30	324.40	12.7	87.3
Ammonium N	1.20	10.90	10.2	89.8
Nitrate N	0.06	0.68	8.7	91.3
Total N	260.30	2048.80	11.3	88.7
Area occupied	--	----	10.1	89.9

These data indicate that windrow zones were not a significant source of nutrients for the next rotation. When these stands were mechanically site prepared following clearcut harvesting, the windrows were incorporated into the site. Cations, nitrogen, and organic matter from the windrows certainly contributed to the overall fertility of the site, but this contribution was not enough to alleviate the need for fertilization.

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ND AND RESOURCE MANAGEMENT ON TYPIC QUARTZIPSAMMENTS [1]

W. David Tracey, David L. Kulhavy, and William G. Ross [2]

Abstract. Survival and growth of seven species/treatment combinations were tested on Tonkawa fine sand (thermic, coated Typic Quartzipsamment) in Nacogdoches County, Texas. In January 1983, seedlings were hand-planted on an intensively prepared clearcut site on the Tonkawa soil series in northern Nacogdoches County. Tonkawa sands serve as recharge zones for the Carrizo aquifer, a major source of clean groundwater for much of East Texas. Intensive management practices on this sensitive site created severe site conditions, providing incentive for the study. Species/treatment combinations were: untreated loblolly (*Pinus taeda* L.) pine (LOB/CON); Terra-Sorb™-treated loblolly (LOB/TER); kaolin clay slurry-treated loblolly (LOB/CLA); untreated slash (*P. elliottii* Engelm.) pine (SLA/CON); Terra-Sorb-treated slash (SLA/ TER); kaolin clay slurry-treated slash (SLA/ CLA); and containerized longleaf pine (*P. palustris* Mill.) (LL/CONT). Treatments were applied as a bareroot dip prior to planting, to increase soil moisture retention near the roots, and subsequently increase survival. Containerized longleaf yielded the highest survival (greater than 50 percent) throughout the study, followed by LOB/TER (38 percent), while all other treatments were unacceptable (below 30 percent by the end of the sixth year). Management recommendations include reforest the site in longleaf pine or allow the natural scrub vegetation to inhabit the site, while managing for nontimber resources, such as groundwater, wildlife, and recreation.

Introduction

In forested areas on deep, dry ds, special management techniques required to establish and main- n a viable forest ecosystem. y droughty sands are classified Quartzipsamments and are found on dhills throughout the Atlantic and Gulf Coastal Plains, from New Jersey southward to Florida and westward to Texas (Burns and Hebb 1972). The original vegetation on the sandhills was an association of longleaf pine (*Pinus palustris* Mill.), turkey oak (*Quercus laevis* Walt.), and bluejack oak (*Q. incana* Bartr.), commonly called "scrub oaks," and pineland threeawn (*Aristida stricta* Michx.), commonly known as wiregrass (Hebb 1957). During the "cut out and get out" era of forestry in the South, stands of longleaf pine were harvested from sandhill sites with no provision made for regeneration. The understory scrub oaks and wiregrass assumed dominance since they are well adapted to

[1] 'aper presented at Sixth Biennial thern Silvicultural Research Con- 'ence, Memphis, TN, Oct. 30-Nov. 1990.

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droughty sands. Subsequent efforts to reforest these sites have met little success, leaving undesirable vegetative cover on these areas.

Droughty sands possess low potential for production of quality timber, due to their low inherent fertility and low water holding capacity. However, the ever-increasing demand for land available for production of food and fiber dictates the necessity to develop effective methods of reforestation of such sites. Conventional forest management techniques usually produce unacceptable results when applied to these droughty sites. Consequently, millions of acres of land that once supported stands of high quality pine timber throughout the Southeastern United States are now covered with scrub oaks and grasses. This greatly reduces the value of the land and its productivity.

The South Carolina State Commission of Forestry has found that successful reclamation of sandy scrub oak land can be accomplished at reasonable costs (Lehockey and Lee 1954). In south and central peninsular Florida, citrus production is the primary land use on droughty sands. Other uses include hay production, certain agricultural crops, and mineral extraction. Several studies have indicated that droughty sites are capable of being reforested with proper management programs. More research is needed to support these findings and to develop more effective methods of establishing forests on Quartzipsamments.

In 1983, a study was initiated in east Texas to develop management strategies for reforestation and alternative land uses of sandhill (Kroll et al., 1985). This report will consolidate the first 8 years of survival and growth results of that study, and will provide management recommendations for Typic Quartzipsamments in this region. These results will allow us to develop effective management techniques that will increase productivity of sandhills, thereby contributing to the worldwide reforestation effort.

Objectives

The central purpose of this study is to develop integrated land use and resource management strategies for Typic Quartzipsamments that are economically as well as ecologically sound and are compatible with the land.

Specific objectives are to:

1. Determine optimum tree species and treatments for reforestation;
2. Recommend practical alternative land uses and management strategies for Typic Quartzipsamments.

Background

In east Texas there are approximately 23,000 ac of soils classified as Quartzipsamments, extending from northern Nacogdoches and Rusk Counties eastwardly into Panola and San Augustine Counties. Tonkawa series, classified as a thermic, coated Typic Quartzipsamment, is characterized by low

ertility, rapid permeability (up to 20 inch/hr), and extremely acid re-
ction. These soils developed on thick, sandy deposits of the Eocene
poch, and presently occur on broad, slightly convex, interstream divides,
th slopes ranging from 0 to 20 percent. In some places, these sands oc-
ur in contiguous units of more than 2,000 ac (Dolozel 1980). Tonkawa
ands developed on an outcrop of the Carrizo formation, an important water-
earing sand that provides an excellent quality groundwater source for most
f the east Texas Basin (Guyton and Associates 1970).

The primary land use on Tonkawa sands is woodland, although the po-
ential is low for pines as well as most cultivated crops due to the
roughty and infertile nature of the sand. Typical site index is 55 for
hortleaf pine (P. echinata Mill.). The most recent forest cover was dom-
nated by shortleaf pine and bluejack oak, with a few natural stands of
ongleaf pine and turkey oak. The longleaf grew mostly near the transition
ones between Tonkawa sands and Osier sands, an associated soil series oc-
urring on concave slopes at the lower elevations of these sandhills (Dolo-
el 1980). Osier soils are also fine sands, but are usually waterlogged
ue to their topographic position with respect to the Carrizo aquifer.
any springs discharge in the Osier sand.

Past Operations

From 1973 to 1975, approximately 6,000 ac on Tonkawa soils in northern
acogdoches and southern Rusk Counties were clearcut, followed by chopping
nd burning on some sites, or scalping with V-blades on others. Site prep-
ration was accomplished primarily by a LeTourneaux tree crusher, or pre-
ared with a drum chopper during the summer prior to planting. In some
reas, a whole-tree chipper was used for complete hardwood and slash re-
oval. Essentially, this removed all organic matter and surface litter
rom the site and exposed bare mineral soil to the sun and wind. This
reatly reduced the moisture-holding capacity of the soil and increased
urface temperature.

Subsequently, from 1974 to 1981 several attempts to reforest the area
sing both machine and hand-planting methods were unsuccessful. Most of
hese plantings were failures (less than 10 percent survival) primarily due
o the droughty site conditions. Minor factors included cottontail rabbit
Sylvilagus floridanus (Allen)], pocket gopher [Geomys bursarius (Shaw)],
nd Texas leaf cutting ant [Atta texana (Buckley)] damage. Town ant pre-
ation is common on droughty sands, where pine seedlings are often the most
ucculent, and during winter are the only green vegetation available (Moser
984). These circumstances provided incentive for this study.

Design And Treatments

Study plots were established in January 1983 to test the survival and
rowth of seven species/treatment combinations on this site. A randomized
lock design was used, in which the same seven treatments were randomly ar-
anged within each of eight replicates. Within each treatment, 48 seed-
ings were planted on a 8 x 8 ft spacing in four rows of 12 seedlings each.

each. The buffer zones were planted with bare rooted loblolly pine seedlings. Detailed plot layout is presented in Kroll et al. (1985).

The seven treatments are:

1. untreated loblolly pine (LOB/CON);
2. Terra-Sorb™-treated loblolly pine (LOB/TER);
3. kaolin clay slurry treated loblolly pine (LOB/CLA);
4. untreated slash pine (SLA/CON);
5. Terra-Sorb-treated slash pine (SLA/TER);
6. kaolin clay slurry treated slash pine (SLA/CL-A), and;
7. containerized longleaf pine (LL/CONT).

Terra-Sorb is a family of starch, or synthetic, absorbent polymers capable of absorbing hundreds of times their weight in water. It is a hygroscopic media that may be used as a root dip to increase the moisture-holding capacity of the soil around seedling roots. Kaolin clay slurry is similar, but an inorganic compound that is also a hygroscopic substance. It is commonly used as a standard packing media for pine seedlings.

Replicates were hand-planted using standard methods in January 1983. No additional site preparation was performed, since the site had been intensively prepared earlier. Survival data were collected in April, June, and December of the first year (1983), and in May, August, and December of the second year (1984). Thereafter, survival counts were taken in May 1985, in August 1986, and in December 1988.

In December 1983, height and root collar diameter measurements were taken for all surviving seedlings except the LL/CONT. During the winter of 1984-1985, four of the eight replicates were accidentally destroyed by fire, reducing the sample size by one-half. Survival and growth rates of the residual replicates were then compared to those that perished in the fire. There was no significant difference in survival or growth, so the results reported here reflect only those data from the residual four replicates. Height and diameter measurements were again taken in December 1988 and October 1990.

Soil samples were collected at random locations within the study plots (TN-1), from another area within the same clearcut (TN-2), and from an undisturbed natural stand (TN-3), all on Tonkawa soil series. Texture analysis by Bouyoucos method was performed for composite samples from each site, at several depths. Results of the texture analysis, reported by Kulhavy et al. (1987), confirm the sandy nature of the soil and classification as a Quartzipsamment.

Precipitation data were obtained from two sources within the area. They correlate relatively well with survival and growth, especially during the first 2 years of seedling establishment.

Data were analyzed on the Honeywell CP6 mainframe computer at Stephen F. Austin State University, SPSS^{x} statistical package. All tests were conducted at the 95 percent confidence level ($P \leq 0.05$).

Survival and growth data were grouped by treatment and replicate, then o-way analysis of variance (ANOVA) was performed to test for significant fects of both variables. As expected, treatment was the effective vari-le in most cases. One-way analysis of variance (ONEWAY) was performed on rvival and growth, using Duncan's multiple range test to identify signif-ant differences between treatments and to determine which treatments dif-red significantly from others.

Survival volume index (SVI) (Tuttle et al., 1987) was calculated for ch treatment (height x root collar diameter^2 x percent survival), with e first- and sixth-year data. SVI was tested for significant differences tween treatments using one-way analysis of variance (ONEWAY), and Dun-n's multiple range test to determine which treatments differed signifi-ntly from others.

Results And Discussion

rst-Year Survival and Growth

First year survival of the seven treatments on Quartzipsamments was gnificantly higher for containerized longleaf (LL/CONT), followed by rra-Sorb-treated loblolly pine (LOB/TE-R), with 85.2 and 79.7 percent, spectively (Fig. 1). Survival rates of the other five treatments were t significantly different, ranging from 54.7 percent for clay slurry-eated loblolly (LOB/CLA) down to 33.3 percent for clay slurry-treated ash (SLA/CLA). Initial survival rates (3 months after planting) were gnificantly higher for LL/CONT, LOB/TER, and Terra-Sorb-treated slash ne (SLA/TER), (97.9, 95.6, and 94.3 percent, respectively), followed by treated slash (SLA/CON), LOB/CLA, SLA/CLA, and LOB/CON, (90.1, 88.0, .9, and 83.1 percent, respectively). By June, LL/CONT and LOB/TER had gnificantly higher survival (96.9 and 95.6 percent, respectively) than e other treatments. This trend continued throughout the 6 years (Fig. . Survival rates based on averages of all eight replicates did not ffer significantly from rates based on four replicates for any of the ven treatments. The overall survival decline between June and October s attributed to the low precipitation levels during that period (Kroll et ., 1985). Although the months of May and June were relatively wet (above rmal precipitation), July through October had lower than normal levels d November and December both had above normal precipitation.

Average height of loblolly was significantly greater than that of slash ter 1 year (Fig. 2), but there was no significant difference in height tween the three treatments within species. The LOB/TER seedlings were ller (0.96 ft), followed by LOB/CON (0.93 ft), and LOB/CLA (0.91 ft). ash seedlings were consistently shorter: 0.79 ft, 0.79 ft, and 0.78 ft, r SLA/CON, SLA/CLA, and SLA/TER, respectively. Mean root collar diameter s significantly greater for slash than for loblolly (Fig. 3). The SLA/N had a significantly larger diameter than the SLA/CLA, but neither of ese was significantly different from the SLA/TER. There were no dif-rences between the three loblolly treatments. Survival volume index, eight x root collar diameter^2 x percent survival) of LOB/TER was signifi-ntly higher than that of any other treatment (Fig. 4). The LOB/CLA was gnificantly different from the other three treatments. Survival volume

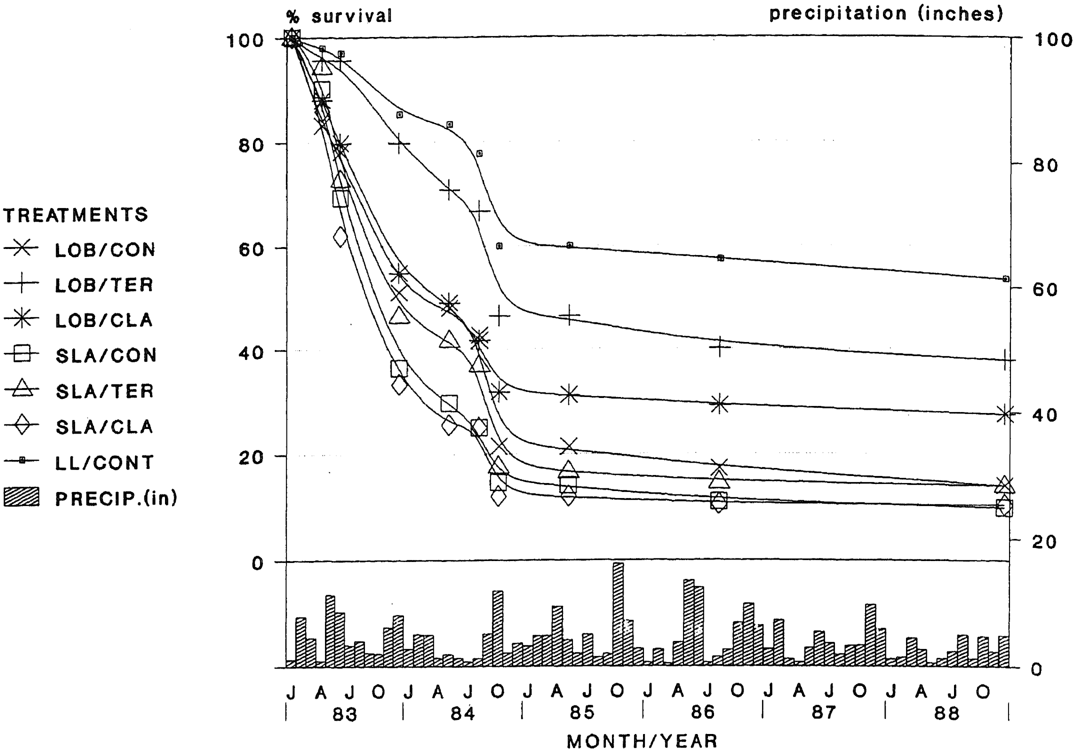


Figure 1. Survival of treated seedlings, 1983-1988, Typic Quartzipsamments.

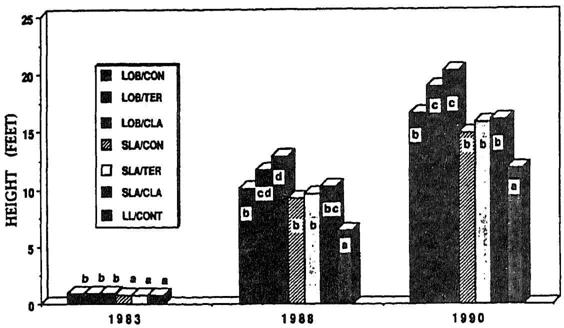


Figure 2. Height, Typic Quartzipsamments, 1983-1990.

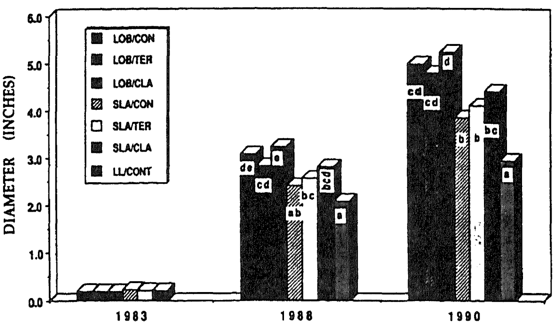
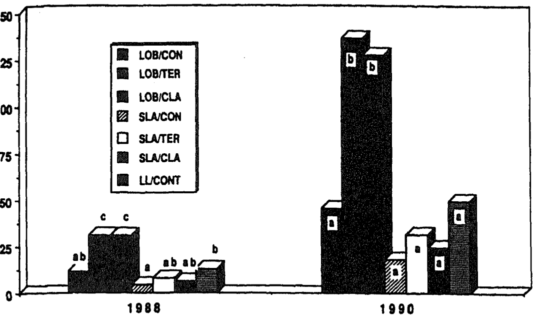


Figure 3. Diameter, Typic Quartzipsamments, 1983-90.

index (SVI), like plot volume index (PVI), serves as an indicator of overall performance in response to each combination of treatments (Walker et al., 1989), but SVI has the advantage of being comparable among sites since it is independent of the number of planted seedlings per plot or treatment (Tuttle et al., 1987).



igure 4. Survival volume index SVI), Typic Quartzipsamments, 988-1990.

Second-year Survival

Total precipitation in Nacogdoches during 1984 was, again, below normal and less than in 1983. Although relatively consistent through the summer, the precipitation levels were too low to provide these highly permeable sands with adequate moisture through the warm summer months. As a result, by October, survival rates had decreased drastically across the site, with LL/CONT and LOB/TER at 59.9 and 46.4 percent, respectively. All other treatments were below 32 percent. Throughout the remainder of the study, all treat-
ents showed less than 10 percent decline in survival, indicating their tability, once established (Fig. 1).

hird- And Fourth-year Survival

While most treatments sustained less than 4 percent mortality over this -year period, the LOB/TER seedlings declined by 6.3 percent, primarily due o defoliation by the Texas leaf cutting ant, or town ant, a pest of pine eedlings (Moser 1984). Damage to pine seedlings occurs mostly during the inter and early spring, while there is little or no other green vegetation vailable to forage. They prefer open areas of deep sandy soils, that are asy to excavate, to build their vast subterranean "towns," which may be everal acres in area and up to 23-ft deep (Moser 1984). Town ant nest unnels extend laterally up to 295 ft or more, but their foraging trails, boveground, may extend hundreds of feet from entrance holes to plants uner attack (USDA 1985).

ifth- And Sixth-year Survival And Growth

After the fourth year, survival rates began to stabilize (Fig. 1). All reatments declined less than 4 percent during the fifth and sixth years. he largest decline in survival was the LL/CONT (-3.7 percent), followed by OB/CON (-3.1 percent), LOB/TER (-2.1 percent), and LOB/CLA (-1.6 percent). he slash treatments declined less than 1 percent. One LOB/TER seedling as cut and removed (unrelated to study), which contributed about ½ percent o the "apparent" decline in their survival. Precipitation is not as critcal a factor once the trees are established. Precipitation levels were elow normal for both 1987 and 1988, with fewer rain days for both years. hese 2 years were considered droughty, not only in east Texas, but hroughout many parts of the Southeast.

Mean height and root collar diameter were larger for the LOB/CLA trees 12.89 ft and 3.24 inches). Average height of LOB/TER (11.71 ft) was secnd in rank, followed by SLA/CLA (10.28 ft), respectively. The shortest rees were the containerized longleaf (LL/CONT) (6.42 ft), but due to the nnately different growth patterns between longleaf and other southern yelow pines, the measurements cannot be effectively compared. Root collar

diameter was significantly larger for LOB/CLA than all other treatments, except LOB/CON (3.08 inches), which was significantly larger than SLA/CON (2.40 inches), SLA/TER (2.56 inches), and LL/CONT (2.08 inches), but not SLA/CLA (2.80 inches). Survival volume index (SVI) was significantly greater for LOB/TER and LOB/CLA trees than for any other treatments. Although LL/CONT trees were shorter and thinner than any other treatment on the average, the high survival rate yielded the third highest SVI (13.06) for this treatment.

Potential evapotranspiration, calculated for the 1951-80 period in Nacogdoches, was compared to normal monthly precipitation levels to determine when water deficits normally occur in the area. January through April have a diminishing water surplus, ranging from +3.69 inches in January to +1.77 inches in April. Water deficit begins in May, with -0.13 inches, increases to -4.56 inches in July, then decreases to -1.11 in September. Water surplus is +0.37 inches in October, and increases to +3.70 inches in December. This indicates the normal long-term water balance and does not take into consideration the site conditions. On the study site, the water balance is more extreme, with smaller surplus values and larger deficits, over longer periods. Although transpiration may be lower, due to lack of vegetation on the site, evaporation is extremely high during the warm summer months due to reflected heat from the exposed sands.

Eighth-year Survival And Growth

Survival rates remained stable after the sixth year. No decline indicates that the trees are well established. Growth rate patterns (both height and diameter) remained consistent also (Fig. 2 and 3). Average heights of the LOB/TER (18.92 ft) and LOB/CLA (20.28 ft) were not significantly different from each other, but were significantly greater than all other treatments. Average heights of LOB/CON (16.63 ft), SLA/CON (14.89 ft), SLA/TER (15.81 ft), and SLA/CLA (16.08 ft) were not significantly different from each other, but were significantly greater than that of LL/CONT (11.90 ft) (Fig. 2).

Average diameters of all three loblolly treatments did not differ significantly from each other, but the LOB/CLA diameter (5.24 inches) was significantly greater than that of the slash and longleaf treatments. The average diameter of SLA/CLA (4.40 inches) did not differ significantly from that of the other slash treatments, LOB/CON (4.98 inches), or LOB/TER (4.79 inches), but average diameter of all loblolly and slash treatments was significantly greater than that of LL/CONT (2.94 inches) (Fig. 3).

Survival volume index (SVI) of LOB/TER (136.35) and LOB/CLA (127.51) was significantly greater than that of all other treatments, while the others did not differ significantly from each other (Fig. 4).

Apparently, all trees in the study are well established and growing vigorously in the eighth year, as indicated by the significant increases in all measurements. Although the harsh site conditions made initial establishment difficult, results indicate that once established, pines are well adapted to the site.

Summary And Conclusions

Based on these results, Typic Quartzipsamments may be successfully re-
orested in pine. Management strategies are simple, but must be adhered to
arefully. On forested sites, the most critical rule is to avoid clearcut-
ing. This results in overexposure of the surface to the sun and drying
inds. Minimum exposure to drying winds conserves moisture and reduces de-
omposition of humus and organic remains (Wilde 1948, 1958). Underplanting
s recommended, followed by deadening of residuals after planted seedlings
re established. Natural regeneration by seed-tree or shelterwood systems
s also recommended for deep, dry sands.

On sites already clearcut, site preparation must be accomplished with
inimal displacement of topsoil. Organic materials must remain on the
ite, since they retain moisture that the sands cannot. Some Typic Quart-
ipsamments have a loamy or clayey layer 6 to 10 ft below the surface which
ill hold some moisture within reach of tree roots. Tonkawa sands general-
y have no such layer, resulting in the characteristic rapid percolation
ates.

The species recommended for reforestation of deep sands in the southern
nited States is longleaf pine. It is well-suited to deep, dry sands, and
istorically inhabited millions of acres of sandhills across the Southern
nd Southeastern United States. Containerized is the planting method of
hoice. It is more time consuming and labor intensive, but generally more
uccessful than other methods.

Results of the root treatments demonstrate their effectiveness in im-
roving survival as well as growth. The Terra-Sorb treatment had a greater
nfluence on survival, while the kaolin clay slurry yielded greater growth.
urther research on the operational use of both of these treatments is rec-
mmended. Planting longleaf with one or both of these treatments is also
ecommended for further research.

Site quality of these droughty sands is obviously low in terms of tim-
er production. Therefore nontimber values of sandhills, such as aesthet-
cs, groundwater protection, and wildlife management should take a higher
riority when developing management plan for such sites. Since these sands
erve as a major recharge zone for an important aquifer, groundwater pro-
ection and development is a viable alternative land use, and is encouraged
o ensure a plentiful supply of clean water for the region. Management
trategies for this option are very simple. Allow the natural scrub vege-
ation to inhabit the site and limit activities that cause runoff and ero-
ion. Prohibit applications of chemicals and disposal of wastes, materials
hich, if leached into the aquifer, would contaminate the valuable water
upply.

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WATER BALANCE IN THE INTERIOR UPLANDS: A STANDARD HYDROLOGIC TOOL PROVIDES EASILY INTERPRETED INFORMATION ABOUT SOIL MOISTURE AND SITE PRODUCTIVITY [1]

Blair D. Orr, Timothy H. Chesnut, and Glendon W. Smalley [2]

Abstract. The water balance, calculated using Thornthwaite's method, was used to analyze soil moisture deficits of representative forest soils of the Highland Rim, Cumberland Plateau, and Ridge and Valley physiographic provinces in Alabama, Georgia, Kentucky, Tennessee, and Virginia. A total of 27 weather stations and three to seven soil types at each station were observed. Rainfall and evapotranspiration records from 30-year averages and dry years in the 1980s were used to compare soils with different water holding capacities. Water holding capacity varied due to differences in depth, texture, and stoniness. During an average year only the shallowest soils in areas with high potential evapotranspiration showed soil water deficits. In dry years most soils exhibited soil water deficits. Those soils in southern portion of the study area, i.e., those with greater evapotranspirative stress, had greater deficits than the more northern portion. Even during a series of dry years forest soils returned to field capacity during the winter months. Thornthwaite's water balance provides a simple, but effective, method of examining soil moisture patterns in forest soils. Graphical presentation of the results aid in interpretation.

Introduction

The United States Forest Service s published six regional forest te classification guides for the terior Uplands (Fig. 1) [Smalley 79, 1980, 1982, 1983, 1984, 1986a; Smalley 1986b (combined ed.)]. rk was underway on a seventh re- onal guide for the southern Ridge d Valley region when the silvicul- ral research project at Sewanee, nnessee, was closed in the fall of 1988. These guides were designed to assist foresters and other land managers in planning decisions.

Each regional guide contains a summary of the vegetation, soils, geology, physiography, and climate. The climate data includes precipitation and temperature records from weather stations where long-term information is available. A water balance for selected sites in each region is a natural extension of precipitation, temperature, and soils data because it integrates these factors into an easily interpreted graph or chart which describes the potential and actual evapotranspiration and the soil water regime.

Paper presented at Sixth Biennial outhern Silvicultural Research Con- erence, Memphis, TN, Oct. 30-Nov. 1990.

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This paper describes the application of Thornthwaite water balance (Thornthwaite and Mather 1955, 1957) as described in Dunne and Leopol (1978) to sites in the Interior Uplands (Fig. 1). The first section is brief review of the literature, including justification of the use c Thornthwaite's method; the second provides a description of the method ar the data involved; the third illustrates the use of the Thornthwaite wate balance to analyze soil moisture regimes for various soils at a single lc cation, and to compare the variation in evapotranspiration and soil mois ture regimes at different latitudes within the Interior Uplands. We cor clude with some general observations and a discussion of the limitations c our study.

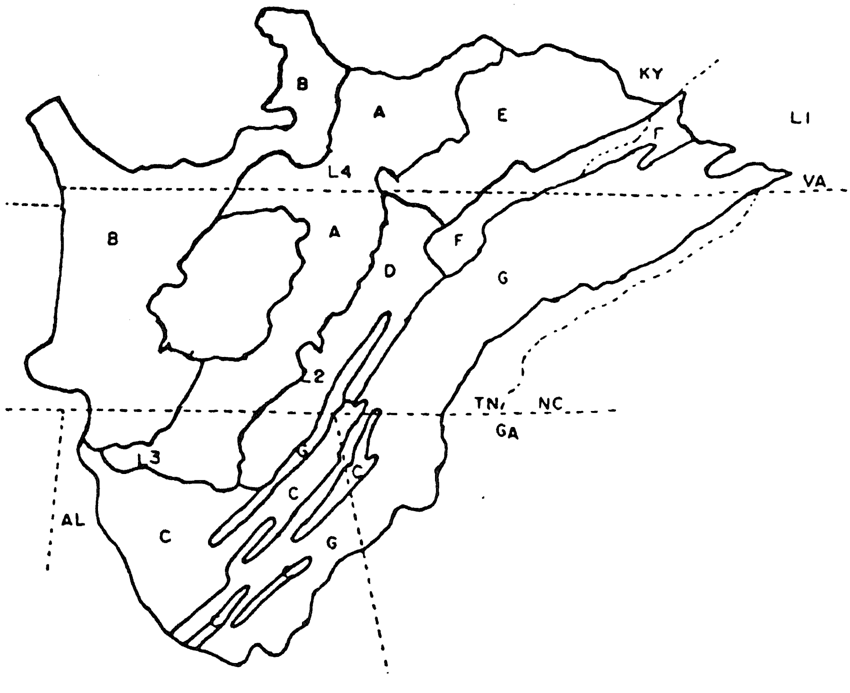

Figure 1. Location of physiographic regions and selected weather stations in the Interior Uplands.

A = eastern Highland Rim and Pennyroyal
B = western Highland Rim and Pennyroyal
C = southern Cumberland Plateau
D = mid-Cumberland Plateau
E = northern Cumberland Plateau
F = Cumberland Mountains
G = southern Ridge and Valley
L1 = Burkes Garden, Virginia
L2 = Monteagle, Tennessee
L3 = Muscle Shoals, Alabama
L4 = Summershade, Kentucky

Background

Many empirical formulae have been developed to calculate potential apotranspiration (Penman 1963). Penman's approach is considered to have e soundest physical basis. However, Thornthwaite's method (Thornthwaite d Mather 1955) has received considerable use because of its simplicity d readily available precipitation and air temperature data. It was the oice for this study.

The influence of soil moisture variability on site productivity and and composition is well established in forestry literature. In 1927, lch reported the combined influence of drought, late frosts, and path-ens on mortality and apparent changes in species composition in mixed oak uercus spp.) stands. Earlier reports of soil, water, and vegetation in-ractions are cited in Millers et al. (1989). Recent advances and refine-nts in water-plant relations are compiled or cited in Balmer (1978), llers et al. (1989), and Grier et al. (1989). While these citations re-r broadly to soil moisture and evapotranspirative stress, the specific e of Thornthwaite's water balance has been applied to land use studies milar to this study (Patric and Black 1968) and to topics of current in-rest, such as the greenhouse effect (Quinones and Hoos 1990).

Methods

Following Dunne and Leopold's (1978) example, a spreadsheet was devel-ed which uses monthly precipitation (P) and temperature data and avail-le soil water to predict monthly potential evapotranspiration (PET), ac-al evapotranspiration (AET), and the soil water deficit. Figure 2 is an ample of the spreadsheet for a 30-year average water balance with climate

Max Soil Moist.= 180 mm   Summershade KY, (Eastern Highland Rim), Ennis silt loam

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.
Precipitation in inches												
1988(in)	3.97	2.85	3.12	3.42	2.39	0.76	3.82	2.32	7.36	2.31	6.3	6.3
dev. (in)	-0.65	-1.1	-2.37	-1.02	-1.96	-3.84	-1	-0.85	3.42	-0.13	2.18	1.58
avg(mm)	117.3	100.3	139.4	112.8	110.5	116.8	122.4	80.5	100.1	62	104.6	119.9
Temperature for PET												
1988(F)	32.7	36.7	47.5	57	64.1	73.7	78.2	78.2	69.2	50.9	49.1	39.5
dev.(F)	-1.8	-1.1	1	-0.3	-1.4	0.8	1.9	3	0	-6.3	2.9	1.1
avg. (C)	1.39	3.22	8.06	14.06	18.61	22.72	24.61	24	20.67	14	7.89	3.56
	Annual Heat Index =			61.398		a =	1.455					

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.
P	117	100	139	113	110	117	122	81	100	62	105	120
PET	2	6	24	53	80	107	121	116	94	53	23	7
P-PET	116	94	116	59	30	9	2	-36	7	9	82	113
Ac Pt WL	0	0	0	0	0	0	0	-36	0	0	0	0
SM	180	180	180	180	180	180	180	150	157	166	180	180
ΔSM	0	0	0	0	0	0	0	-30	7	9	14	0
AET	2	6	24	53	80	107	121	110	94	53	23	7
Deficit	0	0	0	0	0	0	0	6	0	0	0	0
S	116	94	116	59	30	9	2	0	0	0	67	113

Figure 2. Spreadsheet calculations for Summershade, Kentucky, Ennis silt loam, water balance using Thornthwait's method. (Units are mm unless otherwise noted. Annual heat index and a are unitless.)

data from Summershade, Kentucky, in the eastern Highland Rim region, an maximum available soil water for an Ennis silt loam soil. The spreadshee is designed to use available soil water data calculated from the soil in terpretation records for each soil series as published by the Soil Conser vation Service. In all cases, the average available water capacity (inche /inch) for each horizon or group of horizons was used. The calculated val ue is entered as maximum available soil water on line 1. Lines 5, 6, 10 and 11 are read directly from the annual state climatological summaries o the National Oceanic and Atmospheric Administration, located in Asheville North Carolina. The remainder of the spreadsheet, with two exceptions de scribed in the following paragraph, is calculated using equations reporte in Chapter 8 of Dunne and Leopold (1978).

First, PET is calculated as follows:

$$E_i = 1.6 \left(\frac{10T_a}{I} \right)^a ,$$

where,

E_i = potential evapotranspiration in month i (mm/month),

T_a = mean monthly air temperature (°C),

$$I = \text{Annual Heat Index} = \sum_{i=1}^{12} \left(\frac{T_{ai}}{5} \right)^{1.5} , \quad \text{and}$$

$$a = 0.49 + 0.0179I - 0.0000771I^2 + 0.000000675I^3 .$$

Second, the PET values must be corrected for latitude. Our correction assumed that all stations were located at 36° N latitude. Given the mino differences that would have occurred if all stations were corrected fo their actual latitudes, this assumption was justified.

The important parts of the spreadsheet are lines 16 (P), 17 (PET), an 22 (AET), all reported in mm/month. These values can be plotted to give graphical representation of the water balance. Figure 3 is a plot of th data in Figure 2 with mm of AET, PET and P on the vertical axis, and month on the horizontal axis. The shaded area where the AET line rises above th PET line is the soil moisture deficit.

With minor modifications the spreadsheet can be used to calculate a wa ter balance for specific years rather than long-term averages.

Data were entered for 27 weather stations within the Interior Uplands with three to seven soil types at each weather station. A long-term (30 year) water balance and either a 1987 or a 1988 water balance were calcu lated for each soil and weather station. Table 1 illustrates the differ ence between the 30-year average precipitation and temperature and th precipitation and temperature during 1988 at Summershade, Kentucky. Simi lar changes from the long-term average occurred during 1988 and at othe locations.

ky; thirty-year average vs. 1988.

Month	Precipitation		Monthly average temperature	
	1959-1988	1988	1959-1988	1988
	------ (mm) -------		--------- (°C) ----------	
January	117.3	100.8	1.4	0.4
February	100.3	72.4	3.2	2.6
March	139.4	79.2	8.1	8.6
April	112.8	86.9	14.1	13.9
May	110.5	60.7	18.6	17.8
June	116.8	19.3	22.7	23.2
July	122.4	97.0	24.6	25.7
August	80.5	58.9	24.0	25.7
September	100.1	186.9	20.7	20.7
October	62.0	58.7	14.0	10.5
November	104.6	160.0	7.9	9.5
December	119.9	160.0	3.6	4.2

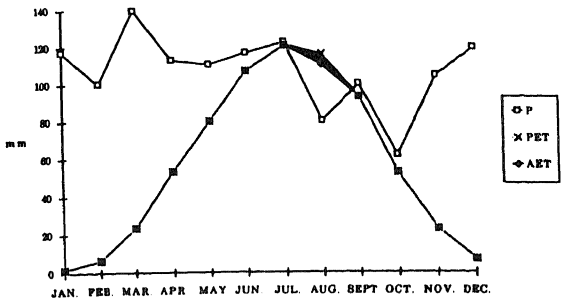

Figure 3. Water balance for Summershade, Kentucky, Ennis silt loam, 1959-1988. (Dotted area indicates soil moisture deficit.)

Results

As the Thornthwaite water balance is a straightforward algorithm, one would not expect to find anomalous results, and we found none. We did find that dry years rather than average years differentiate soils on the basis of water deficits. This is illustrated by observing three different soils on the Cumberland Plateau near Monteagle, Tennessee. Distribution of soils relative to bedrock and elevation on the Plateau are shown in Figure 4.

The Lonewood series (fine-silty, siliceous, mesic Typic Hapludults) consists of deep, well-drained, moderately permeable soils formed in a silty mantle and the underlying loamy residuum of weathered sandstone and shale. These soils occur on broad, undulating, and rolling ridges on the plateau. Slope ranges from 0-12 percent. Vegetation is primarily mixed upland oaks and some natural stands of shortleaf pine (Pinus echinata Mill). Figure 5 shows the average water balance for the period 1958 to 1987. Although PET exceeds P, there is sufficient water stored in the soil to prevent a soil moisture deficit from occurring. In 1987, a particularly dry year, a slight deficit occurs in the summer and autumn (Fig. 6).

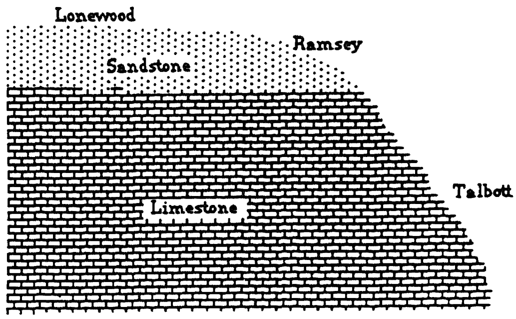

Figure 4. Schematic cross section of the Cumberland Plateau showing location of three typical soils.

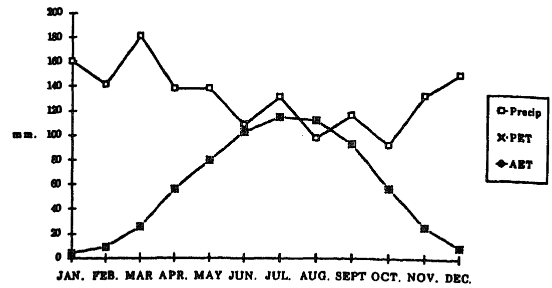

Figure 5. Water balance for Monteagle, Tennessee, Lonewood loam, 1958-1987.

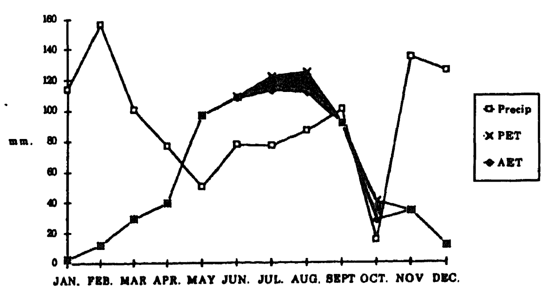

Figure 6. Water balance for Monteagle, Tennessee, Lonewood loam, 1987. (Dotted area indicates soil moisture deficit.)

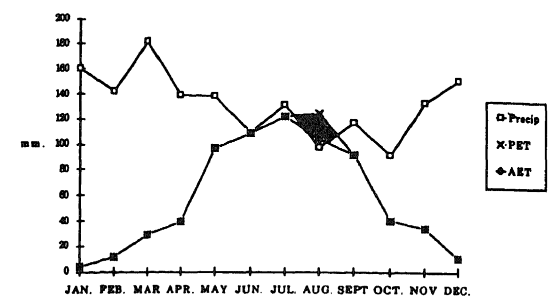

Figure 7. Water balance for Monteagle, Tennessee, Ramsey loam, 1958-1987. (Dotted area indicates soil moisture deficit.)

In contrast, the Ramsey series (loamy, siliceous, mesic, Lithic Dystrocrepts) consists of shallow, somewhat excessively drained soils formed in loamy residuum weathered from sandstone. Permeability is rapid and slopes range from 0-70 percent. The underlying bedrock is close to the surface and is exposed in places. Vegetation is typically poor-quality mixed upland oaks in relatively low-density stands with a grass understory. Mountain laurel (*Kalmia latifolia* L.) is common along the Plateau margins. Figure 7 shows the average water balance for the Ramsey soil and Figure 8 for 1987. A slight deficit occurs in August during average years, and a large deficit occurred throughout the summer and autumn of 1987. It is evident that most vegetation growing on Ramsey soils cannot depend upon moisture stored in the soil.

ilfs), consists of moderately deep, well-drained soils formed in clayey residuum weathered from limestone. They have moderately slow permeability and slope ranges from 0-50 percent. These soils are generally found on the lower third of the Plateau escarpment; often in close association with limestone outcrops. Typical vegetation is a mix of hardwoods dominated by oaks, elms (Ulmus spp.), and ashes (Fraxinus spp.). Eastern redcedar (Juniperus virginiana L.) can be found on drier sites. Figure 9 shows the average water balance for the Talbott soil and Figure 10 for 1987. While Talbott soils are moderately deep, the water balance is similar to the Ramsey soil, though slightly more water is stored in the soil. Though fairly deep, the fine texture and stoniness of the Talbott soil reduces the available water. The result is the substantial summer soil moisture deficit shown in Figure 10.

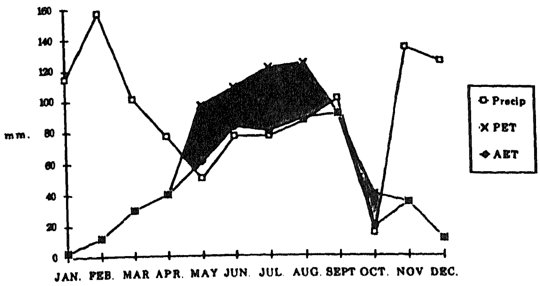

Figure 8. Water balance for Monteagle, Tennessee, Ramsey loam, 1987. (Dotted area indicates soil moisture deficit.)

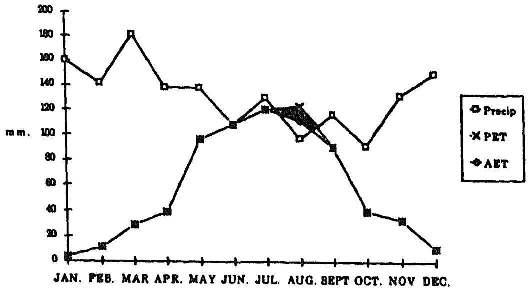

Figure 9. Water balance for Monteagle, Tennessee, Talbott silt loam, 1958-1987. (Dotted area indicates soil moisture deficit.)

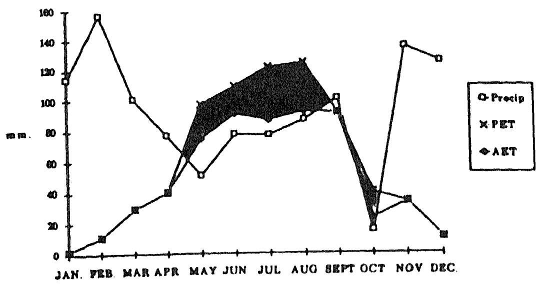

Figure 10. Water balance for Monteagle, Tennessee, Talbott silt loam, 1987. (Dotted area indicates soil moisture deficit.)

A second apparent trend is the variation in water deficit which occurs with a change in latitude. We illustrate this by comparing Dunmore soils at Burkes Garden, Virginia (36°05′N), in the southern Ridge and Valley region, with the Ennis and Mountview soils at Muscle Shoals, Alabama (34°45′N), in the Western Highland Rim region.

The Dunmore series (clayey, kaolinitic, mesic Typic Paleudults) consists of deep, well-drained, moderately permeable soils on level to rolling broad valleys. They have silt loam A horizons and thick clay B horizons formed in residuum from dolomitic limestone. Slope ranges from 3-40 percent. Figure 11 shows the average water balance. No deficit is evident during average years. At

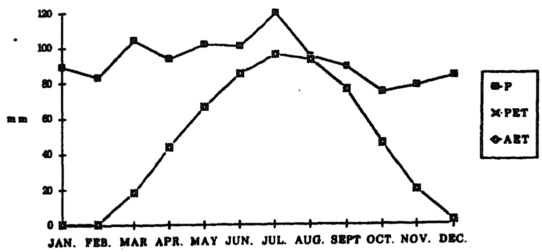

Figure 11. Water balance for Dunmore soil, Burkes Garden, Virginia, 1959-1988 average.

these latitudes moderately deep and deep soils show less stress than similar soils at more southerly latitudes, due to lower evapotranspirative demand.

The Ennis series (fine-loamy, siliceous, thermic, Fluventic Dystrochrepts) consists of deep, silty, well-drained, cherty, moderately rapid permeable soils that formed in alluvial sediments derived from limestone, shale, sandstone and loess. They occur in narrow stream bottoms along first- to third-order streams. Slopes range from 0-5 percent. Coarse fragment content ranges from 35 percent in the solum to 55 percent in the C horizon. These stones reduce the effective soil volume and lower the water holding capacity. Figure 12 shows the average water balance for the Ennis series. Note the soil moisture deficit (the area between the PET and AET lines) during the summer. Thus, even some deep soils show moisture stress in an average year due to higher evapotranspirative demand.

However, no deficit occurs on the average for Mountview soils for the period 1959-1988 (Fig. 13). Mountview soils (fine-silty, siliceous, thermic Typic Paleudults) are deeper than Ennis soils and contain fewer coarse fragments. The additional moisture storage provides a reservoir which is tapped during the higher-stress summer months in order to make up the difference between potential evapotranspiration and rainfall.

Finally, at all locations, winter precipitation fully recharged soil water to field capacity in both the 1987 and 1988 drought years.

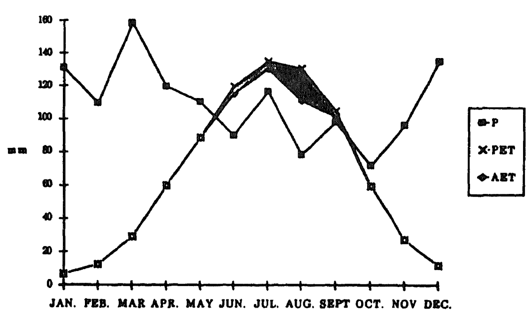

Figure 12. Water balance for Ennis soil, Muscle Shoals, Alabama, 1959-1988 average. (Dotted area indicates soil moisture deficit.)

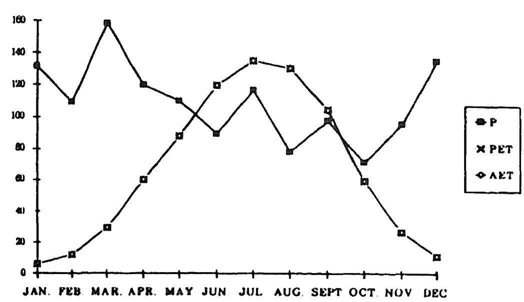

Figure 13. Water balance for Mountview soil, Muscle Shoals, Alabama, 1959-1988 average. (Dotted area indicates soil moisture deficit.)

Discussion And Conclusion

As with any model, certain simplifying assumptions were made which ould be considered when analyzing the results. First, it was assumed at weather station data would be comparable to on-site climatic condions. In general, weather stations were located at lower elevations than e majority of forested land under study. This should mean that these relts are for slighter warmer and possibly drier climates than many forest cro-climates in the particular region. Further, some site-specific charteristics were not modeled. Variation in aspect was not included, alough manipulation of air temperature data used in the model could mimic a ange in aspect. Position on the landscape may increase shading, thereby ducing evapotranspirative stress, or may induce subsurface flow into some tes. Field estimation of subsurface flow and refinement of the water lance model could improve estimates.

We assumed that rooting extended to bedrock or occupied the entire profle described in the soil descriptions. In forest soils, rooting density greatest in the upper horizon and decreases rapidly with depth. A rthcoming summary article about root distribution of various plant species indicates that this assumption is valid (Paul Kalisz, 1990 personal mmunication). Furthermore, Patric et al. (1965) reported early absorpon from uniformly moist soils in the Southern Appalachians and the Piednt was related primarily to root concentration. However, as the soil ied absorption tended toward uniform extraction, even beyond 6-7 m in pth.

Only the 1987 and 1988 drought sequences were studied. It may be that her sequences will give different results. Extended severe droughts may t allow annual soil recharge during the winter months. Either milder or re severe droughts could provide a better descriptive analysis of evapoanspirative stress. Also, monthly data were used. It could be that orter time periods would find evapotranspirative stress periods that are dden when averaged with the other monthly data.

Despite these assumptions and limitations, we believe that the descripion of the environment in the regional forest site classification guides n be much improved by the inclusion of water balances. Thornthwaite's ethod is a widely used hydrologic technique and the necessary data are adily available. Water balances, particularly in graphical form, provide easily understood integration of weather, soil, and the evapotranspiraive demand of vegetation. Finally, the model can be extended to estimate her parts of the hydrologic cycle or can be modified for more sitepecific applications.

Acknowledgments

The authors thank Wayne Clatterbuck and James Patric for their comments n earlier drafts of this paper. All errors remain the responsibility of he authors.

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PREDICTING FOREST TYPE IN BENT CREEK EXPERIMENTAL FOREST FROM TOPOGRAPHIC VARIABLES [1]

W. Henry McNab [2]

Abstract. Four forest types--yellow-poplar (Liriodendron tulipifera L.), scarlet oak (Quercus coccinea Muenchh.), chestnut oak (Q. prinus L.), and a mixture of these and several other upland tree species--were closely correlated with five quantifiable topographic variables measured on-site in Bent Creek Experimental Forest. Elevation, aspect, gradient, and indexes of landform and land surface shape accounted for over 97 percent of the variation in location of forest type centroids in a canonical discriminant analysis. A multivariate discriminant function derived from these variables and applied to an independent validation data set classified more than 75 percent of sites correctly. Soil information from maps--mapping unit, thickness of the A horizon, and solum thickness--was only moderately associated with forest type. Study results suggest that the suitability of southern Appalachian sites for certain forest types may be predicted accurately just on the basis of topographic data measured on-site. Suitability of sites can be predicted by means of geographic information systems because values of the topographic variables can be calculated from a digital elevation data base.

Introduction

Multivariate classification of mountainous landscapes into areas of uniform species composition and productivity is a prerequisite for effective forest management and requires knowledge of the interrelations among vegetation, topography, and soils (Barnes et al., 1982). Soil-site relationships have been extensively studied in the southern Appalachian Mountains and the relationship between productivity and soil and topographic variables has been quantified for many of the important tree species (McNab 1988). However, no one has developed quantitative models for predicting the composition of southern Appalachian stands on the basis of environmental characteristics. Most recently, McLeod (1988) found close correlations of overstory communities with topographic and soil variables in the Black Mountains of western North Carolina, but did not develop prediction models or classification keys. An example of the type of classification needed is available for the Chattahoochee National Forest, where Rightmyer (1988) synthesized information on topographic and edaphic factors affecting site productivity and developed a taxonomic key for identifying sites suitable for broad species groups of conifers, hardwoods, and mixtures. For intensive forest management, however, quantitative models are needed to predict the distribution of forest tree species across the landscape.

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[1] Paper presented at Sixth Biennial Southern Silvicultural Research Conference, Memphis, TN, Oct. 30-Nov. 1, 1990.

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The objectives of this study were to determine correlations of forest ypes with topographic variables in an area of uniform climate and geology nd then develop a discriminant model to predict the occurrence of forest ypes. Another objective was to evaluate mapped soil data as predictors of orest type.

Methods

tudy Area

The study was conducted in Bent Creek Experimental Forest, a 6,000-ac atershed located about 10 miles southwest of Asheville, North Carolina. his area is characterized by short, mild winters and long, warm summers. nnual precipitation averages about 45 inches and is evenly distributed hroughout the year. Geologic formations consist of gneisses and schists f Precambrian Age that have weathered to form a complex, dissected land urface consisting of ridges and coves. Soils, which consist mainly of ltisols with lesser areas of Inceptisols, are generally deep and suitable or a host of hardwood species. The arborescent overstory on dry slopes and idges typically consists of communities dominated by scarlet oak (*Quercus occinea* Muenchh.), chestnut oak (*Q. prinus* L.), black oak (*Q. velutina* am.), blackgum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* (L.) DC.), and sometimes pines (*Pinus* spp.) on disturbed sites. Mesophytic pecies on moist slopes and coves include yellow-poplar (*Liriodendron ulipifera* L.), northern red oak (*Q. rubra* L.), and black locust (*Robinia seudoacacia* L.). Species that occupy both mesic and xeric sites include ed maple (*Acer rubrum* L.), pignut hickory (*Carya glabra* (Mill.) Sweet), logwood (*Cornus florida* L.), and white oak (*Q. alba* L.).

Most timber stands in Bent Creek Experimental Forest have been affected y past settlement. Extensive areas of gentle slopes were cleared for agricultural purposes until about 1900, when land abandonment resulted in onversion to pine-hardwood mixtures on dry sites and yellow-poplar on oist sites. Timber stands on areas of steeper slopes, which were not cultivated or cleared for pasture, were typically grazed and periodically harvested. Following acquisition of the property by the USDA Forest Service, timber stand improvement work was done in selected areas to reduce stocking f undesirable species such as red maple, sourwood, and dogwood.

Field plots used in this study had originally been established for other purposes. In 1950, 126 randomly located 0.2-acre plots were established and measured in stands of upland oaks (Olson, D.F., Jr. Office Report. Growth determinations and related stand data from Bent Creek 0.2-ac plots. March 16, 1960. 16 p.). These plots were remeasured in 1970 (unpublished data provided by D.E. Beck, Principal Silviculturist, Bent Creek Experimental Forest.). Thirty-five additional 0.25-ac plots in even-aged stands dominated by yellow-poplar are part of an ongoing study of growth and yield (Beck and Della-Bianca 1970). None of these plots had been located with regard to topographic characteristics. These 161 plots were defined as the "analysis" plots.

To test the relationships derived, measurements were made in a second group of plots. This "validation" group consisted of 58 randomly selected 0.2-ac plots that had been established in 1950.

Topographic Variables

The following topographic variables were recorded for each plot: Elevation (ft); Slope position (percent); Slope aspect (degrees); Slope gradient (percent); Landform index, and; Terrain shape index. Standard measurement methods were used in most cases. Position on slope was estimated as percent of distance from the main ridge (0 percent) to the valley (100 percent). Aspect was transformed by the method of Beers et al. (1966). A newly-developed index (McNab, in preparation) was used to quantify landform (cove, side slope, ridge). The index is found by determining the mean inclination to the horizon from the plot center. The terrain shape index (McNab 1989) quantifies plot land surface shape. All variables were measured onsite except for elevation, which was determined from U.S. Geological Survey 1:24,000 maps. Mean topographic characteristics are almost identical for both groups of plots (Table 1).

Table 1. Mean and standard deviation (SD) of topographic variables measured on the analysis and validation plots.

Topographic variable	Analysis plots (161)		Validation plots (58)	
	Mean	SD	Mean	SD
Elevation (ft)	2574	309	2543	286
Slope position (percent)	36	29	38	32
Slope aspect (degrees)	145	71	147	67
Slope gradient (percent)	31	15	30	15
Landform index	0.187	0.060	0.189	0.069
Terrain shape index	-0.014	0.052	-0.014	0.065

Soil Variables

Soils in the plots were identified by reference to unpublished 1:12,000 maps produced by the USDA, Soil Conservation Service (Interim soil survey report for Buncombe County, North Carolina, July 1977. 241 pp.). After the mapping unit was determined for each plot, the following physical properties were obtained from the profile description of each soil and grouped by class:

Texture	(sand, clay, loam)
Thickness of A-horizon	(0-2, 2-6, 6+ inches)
Thickness of solum	(0-20, 20-40, 40+ inches).

These properties were selected because they are generally thought to indicate water storage capacity and fertility of the soil available to the trees on the site.

Eleven soil series, grouped into seven mapping units, occur within the study area. However, only one of the mapping units is a single taxonomic series; the others consist of complexes of two or more series. Bent Creek Experimental Forest is perhaps typical of other mountainous areas in the southern Appalachians, where complex topography of small coves and ridges makes mapping small areas of single soil series impractical. Texture of all soil mapping units was described as loam.

ıta Analysis

Stand and topographic data were analyzed with a series of multivariate echniques (SAS 1985). First, the analysis plots were statistically com-.ned into groups of plots having similar species composition. Grouping .ots by forest type is an important phase of the analysis because it can ffect results of subsequent analyses. Also, the cluster analysis can be omewhat subjective because the real membership of plots in each group is sually not known without error. I used PROC FASCLUS to cluster the plots ecause it produces nonhierarchical groups using centroid seed methods and n aid in detecting outlying observations. Threshold values of basal area species were not required, and data were not standardized because all riables were measured in the same units (ft^2). The 35 plots in the rowth and yield study were omitted from the cluster analysis because they ere intentionally located in almost-pure stands of yellow-poplar.

Canonical discriminant analysis (PROC CANDISC) was then used to deter-ine the association of forest types with the measured topographic vari-bles. PROC CANDISC is similar to canonical correlation analysis, which is ommonly used to find the relationship of one set of variables with a sec-d set. In this case, since one set of variables consisted of class val-es, canonical discriminant analysis was the appropriate method. Finally, ROC DISC was used to develop a discriminant analysis model for predicting orest type based on the important topographic site factors identified by eans of PROC CANDISC. The model was tested with data from the validation lots. Forest type of the validation plots was subjectively established by isual inspection of the overstory species composition.

Results And Discussion

luster Analysis

Five forest types were identified in the cluster analysis of the 126 pland oak plots (Table 2). Four types were dominated by a single species f oak (black, chestnut, scarlet, or white). Another forest type, described s mixed oaks, was dominated by combinations of oaks, but also included red aple, yellow-poplar, and black locust, species more commonly associated ith moist sites. Examination of results from the cluster analysis indi-ated a logical assignment of field plots to each type. Two forest types, lack oak and white oak, were represented by less than 15 plots each and ere deleted from further analysis because of insufficient replication of ield plots. With the inclusion of the yellow-poplar type, which was omit-ed from the cluster analysis, 135 plots representing four forest types ere used in succeeding phases of the analysis.

These four forest types (scarlet, mixed, and chestnut oaks, and yel-ow-poplar) are common in Bent Creek Experimental Forest and other regions f the southern Appalachians. McLeod (1988) recognized these and several ther vegetational communities in his study of relatively undisturbed tands in a mountainous region situated about 30 miles northeast of Bent reek. The Society of American Foresters (SAF 1980) also recognizes yel-ow-poplar (57), chestnut oak (44), and scarlet oak (variant of 44) as for-st types, but not mixed oaks.

The canonical discriminant analysis indicated that the locations of the centroids representing the four forest types in multivariate space were significantly different at the 0.01 level. When the centroid means are plotted, along with their 95 percent confidence ellipses, the scarlet oak, chestnut oak, and yellow-poplar forest types form a triangle, with the mixed-oaks type located in the center (Fig. 1). Over 97 percent of the variation in location of centroids was explained by the first two axes. The first axis accounted for about 70 percent of the variation and was closely correlated with landform index (r = 0.79) and terrain shape index (r = 0.72), and somewhat associated with aspect (r = 0.53) and slope position (r = 0.55). The second axis was highly correlated with gradient (r = 0.91) and somewhat associated with elevation (r = 0.67). Examination of topographic variables correlated with the two principal axes indicated that each forest type can be associated with a unique set of topographic features:

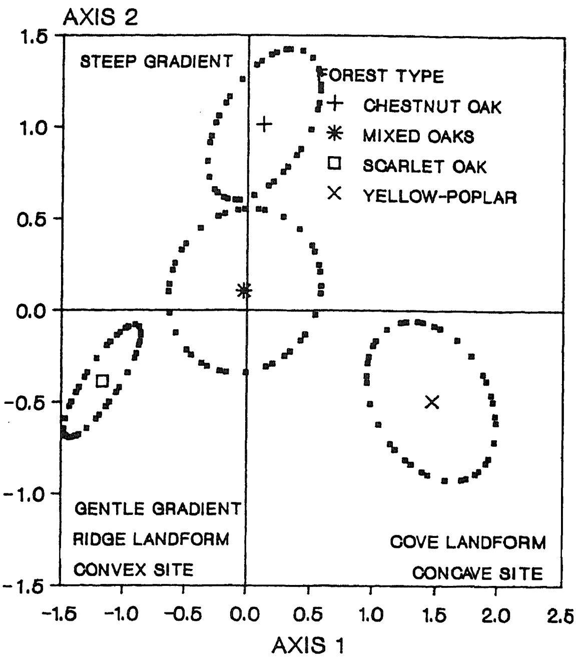

Figure 1. Ninety-five percent confidence limits for centroids of four forest types in relation to canonical axes 1 and 2.

Scarlet oak	Convex sites with gentle gradients on southerly ridges at lower elevations.
Mixed oaks	Linear sites with moderate gradients on side slopes over a range of aspects at low to intermediate elevations.
Chestnut oak	Linear sites with steep gradients on side slopes at higher elevations.
Yellow-poplar	Concave sites with gentle gradients on northerly slopes and coves at intermediate elevations.

Average topographic characteristics for each forest type are presented in Table 3.

Although this study was not designed to determine the environmental factors associated with each canonical axis, a moisture gradient seems to account for distribution of the forest types along axis 1. Scarlet oak, a species typically associated with sites having xeric characteristics (i.e.,

of plots are in parentheses.

Overstory species	Black oak (14)	Chestnut oak (33)	Scarlet oak (47)	White oak (12)	Mixed oaks (20)
	(ft²/ac)				
Black oak	47	6	6	3	11
Chestnut oak	9	50	9	4	11
Scarlet oak	13	8	44	5	10
White oak	10	5	11	46	19
Yellow-poplar	3	3	2	4	10
Red maple	2	4	4	6	9
Black locust	P	3	P[1]	1	6
Hickory spp.	5	2	1	2	4
Sourwood	5	5	4	2	4
Dogwood	1	1	P	P	1
Blackgum	P	1	1	P	1
Yellow pine	5	3	8	P	1
Northern red oak	1	2	0	1	2
Miscellaneous	3	7	P	3	8
All species	104	100	90	77	97

[1]P = present, but contributes less than 0.5 ft^2/ac basal area.

ridges, south aspect) is located at the extreme left end of the axis while yellow-poplar, a species of mesic sites (i.e., coves, north aspect) is situated at the opposite end.

The second axis, which is closely correlated with slope gradient, probably represents a secondary moisture gradient. Chestnut oak is generally considered a dry-site species and occurs on steeper slopes where soil water drainage may be rapid. Slope gradient was one of the topographic variables that strongly separated sites dominated by scarlet oak and chestnut oak. This confirmed earlier observations by Racine (1966).

Discriminant Model

A discriminant model based on the five most important topographic variables measured on the analysis plots (all except slope position) has an overall classification accuracy of about 65 percent (Table 4). Slope position was deleted from the variable set because its effects were accounted for by the landform index. The model is omitted because it is based on a relatively small sample size and is considered to be preliminary. The highest classification successes were for scarlet oak and yellow-poplar forest types, at opposite ends of the moisture gradient. The lowest classification successes were in the chestnut oak and mixed-oaks types, which is logical because they occupy sites with environmental conditions about midway between the other types.

Table 3. **Mean topographic characteristics of the forest types studied.**

Topographic variable	Scarlet oak	Mixed oaks	Chestnut oak	Yellow-poplar
Elevation (ft)	2413	2580	2786	2658
Slope position (percent)	27	34	26	59
Slope aspect (degree)	165	148	144	115
Slope gradient (percent)	24	33	44	30
Landform index	0.148	0.206	0.196	0.237
Terrain shape index	-0.039	-0.021	-0.013	0.033

Table 4. Results of applying the discriminant model to predict forest type on the analysis and validation plots.

Actual forest type (plots)	Predicted forest type			
	Scarlet oak	Mixed oaks	Chestnut oak	Yellow-poplar
	(percent)			
	Analysis plots			
Scarlet oak (47)	70	15	11	4
Mixed oaks (20)	10	60	20	10
Chestnut oak (33)	12	15	61	12
Yellow-poplar (35)	9	16	6	69
	Validation plots			
Scarlet oak (16)	81	19	0	0
Mixed oaks (10)	10	70	10	10
Chestnut oak (18)	6	16	72	6
Yellow-poplar (14)	0	25	0	75

The discriminant model performed slightly better when applied to the validation plots, averaging about 75 percent classification success. The pattern of prediction success was similar to that for the analysis plots, ranging from highest classification success for the scarlet oak forest type and lowest for mixed oaks. One explanation for the improved performance of the model with the validation data is that the evaluations of species composition were based on an area larger than the 0.2-ac plot used for the analysis plots, thereby obtaining a better estimate of forest type occupying the site. However, cover types of the validation plots were determined subjectively, and may have been classified inaccurately in some cases.

Forest Types and Soils

None of the four forest types was associated with a specific soil mapping unit that could be used for prediction (Table 5). For example, over 20

ercent of the plots of each forest type occurred on the Evard-Saluda com-lex. Except in the case of chestnut oak, a similar relationship was pres-nt for forest types on the Tusquitee-Tate-Brevard mapping unit. In gen-ral, over 70 percent of the plots in each forest type were associated with oil mapping units that also supported other forest types. Because most oils in Bent Creek have relatively thick A-horizons and deep solums, for-st types were not closely associated with these soil physical properties.

Table 5. Distribution of analysis plots by forest type and soil mapping unit.

Mapping unit (plots)	Scarlet oak	Mixed oaks	Chestnut oak	Yellow-poplar
	(percent plots)			
Edneyville-Porters (19)	2	20	26	3
Evard-Saluda (44)	26	20	36	23
Hayesville (34)	38	15	9	6
Porters-Jeffrey (1)	0	0	0	3
Tate-French (4)	4	5	4	3
Tusquitee-Spivey-Hayesville (18)	0	10	16	25
Tusquitee-Tate-Brevard (41)	30	30	9	37
All mapping units	100	100	100	100

There are several plausible explanations for the weakness of the rela-ionship between forest type and soil. First, excessive variability may be ssociated with data used in the comparisons because soils are mapped as omplexes instead of individual series. More importantly, however, soil dentifications were obtained from maps, and not "on-site" as were topo-raphic data. The value of on-site soils data is evident from a study by oolittle (1957), who reported close association of scarlet-oak site qual-ty with thickness of the A-horizon in Bent Creek Experimental Forest. For he present, however, because forest types occur across many mapping units nd because these units are broadly defined, information from soil maps oes not complement topographic variables for predicting forest type in ent Creek Experimental Forest.

Summary And Conclusions

Occurrence of four forest types in Bent Creek Experimental Forest was ighly correlated with topographic variables measured on-site. However, orest types were poorly correlated with soil taxonomic mapping units and hysical properties associated with soils. A discriminant function correct-y classified about 75 percent of sites in a validation data set and this ndicates that it may be feasible to develop a classification system based ainly on observable features of mountainous landscapes.

Results of this study can be applied in the field or by geographic information system (GIS) technology. Field measurements of the five most important topographic variables can be obtained onsite in less than 4 minutes using only a compass and clinometer. Application of these results by GIS also seems promising because all topographic variables can be estimated from digital elevation data sets. However, accuracy of prediction will likely decrease in GIS applications because the topographic variables will be estimated using algorithms and will not be measured onsite.

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